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TECHNICAL NOTE

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A METALLURGICAL INVESTIGATION OF FIVE FORGED GAS-TURBINE DISCS OF TIMKEN ALLOY

By J. W. Freeman, E. E. Reynolds, and A. E. White

University of Michigan

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SUMMARY

It has been found that the properties of heat-resisting alloys are dependent to a large extent on the conditions of fabrication. Because the large size of certain gas-turbine rotors has introduced fabrication procedures for which information is not available, a research program was begun at the University of Michigan to ascertain the properties of the better alloys in the form of large forgings. Tests reported in the present paper were made to determine the reproducibility of properties from disc to disc made by different companies and to investigate the effect of various fabrication procedures on the disc properties. The properties of five discs of Timken alloy were determined at room temperature and 1200° F. The tests included short-time tensile, stress-rupture, creep, and hardness along with a metallographic examination of the materials before and after testing.

It appears from the data that Timken alloy discs, which are hot-cold-worked after hot-forging and made from different heats by different companies, will have similar properties. The properties of the discs are lower than those obtained from presumably similarly processed bar stock on the basis of tensile and rupture characteristics. Comparison on the basis of rupture strengths of the Timken alloy discs with three other discs previously studied showed the Timken discs to be better than a CSA alloy disc, similar to a 19-9DL disc, but not so good as a low-carbon N-155 alloy disc.

INTRODUCTION

During the course of a research investigation of the development of heat-resisting alloys for use in turbosupercharger and gas-turbine applications, it has been found that the properties of promising alloys are dependent to a large extent on the conditions of fabrication. Because the large size of certain gas-turbine rotors introduced fabrication procedures for which information was not available, a research program is in progress to ascertain the properties of the better alloys in the form of the large forgings required.

Several papers have previously been issued on discs of alloys 19-9DL, CSA, and low-carbon N-155. (See references 1 to 4.) The present report gives the results of a study of the properties at room temperature and 1200° F of five gas-turbine discs made from Timken alloy. This alloy has been used in the form of discs for actual service in gas turbines. The purpose of the investigation was to determine the reproducibility of properties from disc to disc made by different companies and to investigate the effect of various fabrication procedures on the disc properties. Another aspect of the investigation was a comparison of the disc properties with those from previous investigations on similarly processed bar stock.

This work was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

DESCRIPTION OF DISCS

The available information concerning the chemical composition of the five discs of Timken alloy is summarized as follows: (The first analysis listed for disc C3B-441 was reported by The Canton Drop Forging and Manufacturing Company; the second, by the General Electric Company.)

Serial number	Heat number	Chemical composition (percent)								
		C	Mn	P	S	Si	Cr	Ni	Mo	N_2
S451	H-4315	0.10	1.24	0.022	0.022	0.72	16.56	25.75	5.80	0.12
C0713	13356	.094	1.90	.024	.012	.70	16.60	25.08	5.86	.141
C3B-441	13060	.096 .07	1.74 1.60	.019 .010	.018 .017	.62 .68	17.14 17.25	25.62 25.38	6.18 6.38	.182 .19
H-4174-7A	H-4174	.11	1.49	.023	.023	.64	15.67	26.25	6.25	.111
S1509	H-4684	.12	1.12	.017	.014	.71	15.90	26.20	6.30	.110

The following information concerning fabrication procedure and source was supplied with the discs:

The Midvale Company forged disc S451 as a contour forging. Presumably this disc was hot-cold-worked after hot-forging. It was machined to size at the Everett Plant of the General Electric Company. Because of a slight internal burst at the very center, revealed by X-ray inspection, the disc was rejected for service and cut up for testing. The General Electric Company supplied one-fourth of the disc to the University of Michigan for the present investigation.

The heat of disc C0713 was made by The Timken Roller Bearing Company. The Canton Drop Forging and Manufacturing Company forged the disc as a contour forging. The disc weighed 345 pounds. The following schedule was used in forging the disc: The disc was charged to a furnace at 1850° F and held 4 hours; temperature raised to 2000° F and held $1\frac{1}{2}$ hours, followed by 18 blows in flat dies. The forging was returned to a furnace at 2000° F for $2\frac{1}{2}$ hours followed by 10 blows on the first blocker. After 2 more hours in the furnace at 2000° F, the disc was given 17 blows on the second blocker and then placed on the ground to cool. The disc was charged to a furnace at 1250° F and held $7\frac{1}{2}$ hours, followed by 21 forging blows. It was transferred directly from the forging hammer to a furnace at 1200° F for a 10-hour stress-relief anneal. The disc was supplied by the U. S. Air Forces, Air Materiel Command.

The C3B-441 disc was forged as a contour forging by The Canton Drop Forging and Manufacturing Company. It was hot-worked at 2000° F; then solution-treated 2 hours at 2150° F and water-quenched. It was then cold-worked at 1250° F, stress-relief annealed for 10 hours at 1200° F and air-cooled. Inspection of the disc by etch test, X-ray, Zyglo, and supersonic methods was satisfactory. One slight fold on the entrance side near the stub shaft was shown by Zyglo. One-half of the disc was supplied for this investigation by the General Electric Company.

The Midvale Company made disc H-4174-7A as a cheese forging. Presumably this disc was hot-cold-worked after hot-forging. It was machined to size at the Everett Plant of the General Electric Company. It was rejected for service after X-ray examination because of a defective center. The section being tested was cut so as to avoid most of the defective center. The rim of the disc had been cut off so that the diameter of the section submitted was only about 20 inches. A one-eighth section of the disc was supplied by the General Electric Company.

The S1509 disc was made by the Midvale Company from a 2620-pound 16-inch-diameter ingot, bottom poured. The forging was made from the bottom block from the ingot. It was forged at 2000° F, cold-worked at 1275° F, and stress-relieved at 1200° F. This wheel was rejected by gamma-ray examination. One-half of the disc was supplied by The Midvale Company at the request of the General Electric Company.

Sketches which give the dimensions and relative sizes of the sections of the five discs are shown in figures 1 to 4. Although all five discs are large forgings, for convenience, the three discs S451, C0713, and C3B-441, which have the lesser diameters, are referred to herein as the "small" discs and discs H-4174-7A and S1509, which have the greater diameters, as the "large" discs.

EXPERIMENTAL PROCEDURE

Since the object of the investigation was to evaluate the properties of the discs, a testing program was agreed upon which consisted of (1) tensile tests at room temperature and 1200° F, (2) rupture tests at 1200° F, (3) creep tests of 1000-hour duration at 1200° F under stresses of 20,000 and 25,000 psi, (4) hardness, tensile, and rupture tests to show the uniformity of the disc material, and (5) stability tests on the specimens after testing. The major emphasis was placed on the properties of radial specimens from near the rim of the disc because the rim is heated to the highest temperatures during service. Some modification of this general procedure was made necessary by the types of sample supplied and the nature of the results from individual discs.

Hardness surveys and tensile and rupture tests of specimens from representative locations in the discs were used for the uniformity studies. Data of stress and time for total deformation were obtained from the elongation curves from the rupture and creep tests. Stability characteristics were based on hardness, tensile, impact, and metallographic examination of the specimens after testing. The specimens used for the metallographic examination were etched with a solution of aqua regia in glycerine.

The necessary test specimens were obtained from coupons cut from the discs as shown in figures 1 to 4. These drawings show the locations of the specimens and the identifying code. In the codes, W, X, Y, and Z refer to the locations of the coupons with respect to the faces of the discs. Tensile and creep tests were conducted on standard 0.505-inch-diameter specimens. The specimens for rupture tests were 0.160 inch in diameter and were obtained by splitting a $2\frac{3}{4}$-inch length from coupons into quarters in a lengthwise direction.

RESULTS

Hardness Surveys

The two discs, S451 and C0713, which had been hot-cold-worked in the as-forged condition had approximately the same hardness characteristics. (See table I and figs. 5 and 6.) The tensile test specimens averaged a Brinell hardness of 250 to 260 although the survey of disc S451 showed considerably more variation. The disc C3B-441, which was solution-treated prior to hot-cold-work, averaged higher in hardness than the other two small discs, most of the test specimens having a Brinell hardness from 270 to 300. (See table I and fig. 7.) The hardness surveys showed that two of the discs, C0713 and C3B-441, were harder near the center than at the rim, while disc S451 was harder near the rim.

The hardness of the large disc H-4174-7A, determined on tensile specimens taken from a position midway between the center and rim, was relatively lower than for the other discs. However, the other large disc, S1509, had a Brinell hardness near the rim from 250 to 270 (fig. 8), which was similar to that of the small discs.

Short-Time Tensile Properties

The tensile properties at room temperature and 1200° F are presented in table I. Curves of stress against strain from the tensile tests are included as figures 9 to 12.

The tensile properties at room temperature of discs S451 and C0713 and disc S1509 were similar. Tensile and 0.02-percent-offset yield strengths for these discs were approximately 122,000 and 75,000 psi, respectively. Disc C3B-441, which was solution-treated prior to hot-cold-work, had tensile and yield strengths of approximately 135,000 and 80,000 psi. The disc H-4174-7A, for which the tensile specimens were not representative of rim material, had tensile and yield strengths of approximately 112,000 and 62,000 psi. The ductilities of the tensile tests on material from near the rim were similar. The elongation averaged from 15 to 20 percent.

Specimens from various positions in the discs were tested. There was only a slight tendency for higher strength and ductility observed in tangential over radial specimens at the rim. Specimens from near the center of discs C0713 and C3B-441 had very low ductility but strengths similar to specimens from other locations. Tests were not made on specimens from the centers of disc S451 and the two large discs because they had been rejected for unsoundness at the center.

At 1200° F the tensile properties of the various discs were in the same relative order as at room temperature. Tensile and 0.2-percent-offset yield strengths of discs S451 and C0713 and disc S1509 were approximately 80,000 and 64,000 psi, respectively, while those of disc C3B-441, which was solution-treated prior to hot-cold-work, were 87,000 and 71,000 psi. Disc H-4174-7A had tensile and 0.2-percent-offset yield strengths of 72,000 and 57,000 psi for specimens taken midway between the center and rim. All the discs had similar or higher ductility at 1200° F than at room temperature except the solution-treated and hot-cold-worked disc C3B-441 which was lower in this respect.

Rupture Test Characteristics

The rupture test results at 1200° F for the five Timken alloy discs are given in table II. These results are plotted to logarithmic coordinates of stress against time for rupture in figure 13. Rupture strengths of the discs obtained from the curves of figure 13 and the rupture test ductilities are given in table III.

The three small discs had strengths for rupture in 100, 1000, and 2000 hours in the order of 44,000, 33,000, and 30,000 psi. The solution-treated and cold-worked disc, C3B-441, had the highest rupture strengths of the three at longer time periods, while disc C0713 was the weakest of the small discs. The elongations to rupture in 1000 hours for discs S451, C0713, and C3B-441 were 10, 5, and 3 percent, respectively. Disc S1509 had strengths as high as the strongest small disc, along with an elongation to rupture in 1000 hours of 30 percent. Specimens taken midway between the center and rim of the other large disc, H-4174-7A, gave lower rupture strengths.

Rupture specimens from various positions in the small discs were tested to show uniformity at stresses which would cause fracture of the radial specimens near the rim in the center plane of the respective discs in approximately 100 hours. Specimens from small discs from the four positions listed in table II had rupture times of from 112.5 to 237 hours, an indication that the small discs tended to be weakest in a radial direction in the center plane near the rim. No one location in the three discs seemed to be consistently stronger than other positions, although the tangential specimens near the rim did appear to be strongest in most cases. One tangential specimen in disc S1509 ruptured in a shorter time period than that for radial specimens. Specimens from the center of the large discs were not tested because this portion of the discs was unsound.

Time-Deformation Characteristics

Curves of stress against the logarithm of the time required for various total deformations at 1200° F for the five discs are shown in figures 14 to 18. The total deformations for which curves are plotted are 0.2, 0.5, and 1.0 percent. These curves, along with the curve of stress against rupture time and the curve showing time of transition from second- to third-stage creep, which are included in each figure, give a basis for design of turbine discs on permissible deformation tolerances.

The curves of stress against the logarithm of the time for total deformation were plotted from the data in table IV. These data were taken from time-elongation curves for creep and rupture tests. Time for total deformations of 2 and 5 percent are also shown in table IV. The stresses to cause the various total deformations in time periods of 1, 10, 100, 1000, and 2000 hours, defined by the curves of stress against time for total deformation (figs. 14 to 18), are shown in table V. Comparative stresses to cause a total deformation of 0.5 percent in 1000 hours for discs S451, C0713, and C3B-441 were 21,500, 20,500, and 26,700 psi, respectively. Corresponding strengths for discs H-4174-7A and S1509 were 23,400 and 21,600 psi.

Creep Strengths

Data taken from time-elongation curves, including total deformations in 100, 500, and 1000 hours and creep rates at 500 and 1000 hours at 1200° F, are shown in table VI. The creep rates at 1000 hours were not minimum rates for the higher stress tests of the large discs. The creep strengths obtained from the logarithmic curves of stress against creep rate in figure 19 were as follows:

Disc	Stress for creep rate of 0.0001 percent/hr (psi)
S451	11,500 (estimated)
C0713	14,500 (estimated)
C3B-441	26,000
H-4174-7A	18,200
S1509	11,000 (estimated)

While disc C3B-441, which was solution-treated prior to hot-cold-work, had the best creep and total-deformation properties, the data were quite erratic, and greater caution in the application of these data to design would be necessary than for the other discs.

Extrapolation to 10,000 hours of the transition curves of figures 14 to 18 indicates the stresses which will cause third-stage creep to occur at this time period. Comparison of these stresses with the creep strength for a rate of 0.0001 percent per hour indicates that the creep strengths for the three small discs are safe for use for time periods up to 10,000 hours. A similar comparison for the two large discs indicates that increasing creep rates are to be expected after only 2000 and 5000 hours under stresses corresponding to the tabulated creep strengths.

Stability Characteristics

The effect of creep and rupture testing at 1200° F on room-temperature physical properties and on the microstructure of the Timken alloy discs was used to evaluate the stability characteristics of this material. Some of the completed-creep-test specimens were used to determine the changes in the tensile properties, hardness, and impact properties of the material during creep testing. These results are shown in table VII.

The room-temperature yield strengths, tensile test ductility, and impact strength of all the discs were decreased by creep testing at 1200° F. The original Izod impact strength for all the discs was approximately 9 foot-pounds. The Izod impact strengths of the small discs decreased during creep testing to from 2 to 5 foot-pounds, while the large discs showed very little change in impact strength. The tensile strengths of the three small discs after creep testing were considerably higher than the average of the original specimens, while the two large discs had slightly lower tensile strengths after creep testing. The hardness changes during testing for the five discs showed the same relative variations as the tensile strengths.

Photomicrographs of the original material and completed-creep- and rupture-test specimens are shown in figures 20 to 29. Original microstructures are representative of the structure near the rim and near the center of the discs with the exception of disc H-4174-7A. There was considerable variation in grain size between the small discs and within any one disc. The grain sizes near the rims of the small discs were 4 to 5 for S451, 5 to 8 for C0713, and 3 to 4 for C3B-441. The center structure for each of these discs was at least one grain size larger than the rim structure. Disc C3B-441, which was solution-treated before hot-cold-working, had fewer but larger particles of excess constituents than the other discs; however, this disc had a well-dispersed pattern of very fine particles which was present to a small extent in only one other disc, S451. The large discs had a grain size approximately that of the finest grained small disc.

During testing a tremendous amount of precipitation occurred in the three small discs. (See figs. 21, 23, and 25.) The solution-treated and hot-cold-worked disc, C3B-441, had a heavier but finer precipitate than the other two. The two large discs showed comparatively little precipitation during testing. (See figs. 27 and 29.)

DISCUSSION OF RESULTS

Tension tests have been used to determine the properties at 1200° F of five discs of Timken alloy. These properties, including tensile, rupture, and time-deformation data, may be used as a basis for design of similar discs of Timken alloy.

One of the main purposes of this investigation, aside from the determination of the actual properties of discs as they are put into service, was the study of the variation in properties between heats and fabrication procedures used in the production of turbine discs from Timken alloy. All the tables of data in this report have been prepared so as to show these variations in properties of the discs. In making a comparison of the discs, it is advisable to omit, for the most part, disc H-4174-7A. Material tested from this disc was taken from midway between the center and rim while rim material from the other four discs was used for test specimens. This disc was a cheese forging, while the other four were contour forgings.

Three of the discs, small discs S451 and C0713 and large disc S1509, were fabricated in similar manners by hot-cold-working after hot-forging. These discs, produced from three different heats, had very similar properties with the possible exception of the time-deformation characteristics of the S1509 disc being rather low. It appears, therefore, that Timken alloy discs, produced as these were from separate heats and by two different concerns, possess a satisfactory reproducibility of properties.

Disc C3B-441, which was solution-treated before hot-cold-work, had higher strengths but lower ductility than the other discs. Since only one disc in this form was studied, it would probably be better to have additional data for solution-treated and hot-cold-worked Timken alloy discs before making comparisons of properties between disc treatments.

One outstanding difference in the behavior of the small and large discs was in stability characteristics, as determined by changes in microstructure and room-temperature physical properties during long time testing. The large discs showed very little change in microstructure, impact strength, or hardness during testing, although the tensile test ductility decreased. On the other hand, a large amount of precipitate occurred in the structure of the small discs; the impact strength and tensile test ductility decreased, and the hardness increased markedly during testing. However, as is shown by the early occurrence of third-stage creep for the large discs in comparison with that for the small discs, the so-called structural instability was beneficial to the high-temperature properties of the small discs. This is in line with the general theory that the precipitation phenomenon occurring in high-strength high-temperature alloys is an important factor in developing their outstanding properties.

Another possible comparison is between the properties of bar stock and the discs of Timken alloy. Table VIII lists comparative tensile and rupture properties at 1200° F for the bar stock and the two types of disc. It shows that the disc properties are enough lower than those of presumably similarly processed bar stock to make design of the discs on the basis of bar-stock properties rather risky. However, data on material from the same heat of bar stock which was solution-treated and aged but not hot-cold-worked show properties lower than those of the weakest disc. This indicates that possibly the properties of discs also could be reduced to an unsafe degree by improper fabrication procedure, even though the discs of this investigation have similar and satisfactory properties. Comparison of time-deformation data between discs and bar stock is not possible because of the lack of such data for bar stock.

Table VIII also contains, for comparative purposes, the tensile and rupture properties for three other discs previously studied. (See references 1 to 3.) The room-temperature tensile properties of the Timken alloy discs are higher than those of the 19-9DL, CSA, and low-carbon N-155 discs. The rupture strengths of the Timken alloy discs are better than those of CSA alloy, similar to those of 19-9DL alloy, but less than those of low-carbon N-155 alloy. This comparison is not too satisfactory because of the fact that the discs were not fabricated similarly. The 19-9DL, CSA, and low-carbon N-155 discs were cheese forgings, while all the Timken alloy discs were hot-cold-worked contour forgings, with the exception of the disc H-4174-7A.

CONCLUSIONS

In an investigation conducted at the University of Michigan, the properties at room temperature and 1200° F of five discs of Timken alloy have been determined. The data obtained include tensile properties, rupture test characteristics at 1200° F, and time-deformation characteristics in creep and rupture tests at 1200° F.

From the data it appears that Timken alloy discs in the hot-forged and hot-cold-worked condition have satisfactory reproducibility of properties. This is true for both small and large discs with the exception of the time-deformation characteristics for the large discs, which seem to be lower.

A small disc which was solution-treated prior to hot-cold-work had higher properties than the discs which were forged and hot-cold-worked, but it would probably be better to obtain additional data for other similar discs before making comparisons of strengths between discs or reproducibility of properties.

The properties of the discs are lower than those of presumably similarly processed bar stock on the basis of tensile and rupture properties.

Rupture strengths of the Timken alloy discs are higher than those of a CSA alloy disc, similar to those of a 19-9DL disc, but not so high as those of a low-carbon N-155 alloy disc.

University of Michigan
Ann Arbor, Mich., October 24, 1946

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TABLE I

SHORT-TIME TENSILE PROPERTIES OF TIMKEN ALLOY DISCS

Disc	Specimen number	Specimen location (a)	Temperature (°F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness
					0.02 percent	0.1 percent	0.2 percent				
S451	1Y	CRR	Room	120,500	77,000	89,000	93,500	55,000	11	17.0	252
	1X	SRR	Room	122,000	68,000	83,500	90,000	42,500	14	15.8	254
	6X	SRR	Room	124,375	77,500	87,500	92,000	57,500	16	21.8	258
	6Z	SRR	Room	124,250	83,000	92,000	96,000	65,000	13.5	26.1	250
	9Y	CTR	Room	126,250	78,000	91,500	98,000	57,500	18	21.6	254
	9Z	STR	Room	125,000	84,500	92,500	94,000	65,000	17.5	24.0	261
	3Y	CRR	1200	79,000	------	61,000	63,500	37,500	16	26.1	---
	9X	STR	1200	81,200	------	62,000	65,200	37,500	21.5	30.8	---
C0713	3Y	CRR	Room	122,400	76,500	91,200	96,000	52,500	17.5	25.4	247
	6Y	CRR	Room	121,850	78,000	90,000	95,000	57,500	12.5	16.5	258
	3X	SRR	Room	121,500	75,000	90,000	96,000	52,500	20.5	31.8	259
	6Z	SRR	Room	118,875	67,500	84,000	90,000	37,500	16	27.3	263
	9Y	CTR	Room	121,250	60,000	79,000	86,500	27,500	22.5	26.4	244
	9Z	STR	Room	125,000	74,000	89,000	95,500	55,000	19.5	24.2	253
	8Y-C	CRC	Room	118,350	77,000	91,500	97,000	37,500	9	11.5	245
	8Y	CRR	1200	84,000	------	60,000	64,000	15,000	20	25.8	---
	3Z	SRR	1200	77,750	------	58,500	63,000	22,500	21	32.1	---
C3B-441	3Y	CRR	Room	136,000	80,600	95,000	101,000	50,000	18	21.2	269
	3X	SRR	Room	133,500	81,300	93,700	98,800	62,500	21	19.9	288
	6Z	SRR	Room	137,750	81,000	95,000	100,500	52,500	21.5	31.1	299
	9Y	CTR	Room	136,500	77,000	90,500	96,500	62,500	20	19.9	274
	9Z	STR	Room	137,250	80,000	92,500	96,500	62,500	20.5	21.4	269
	10Y	CRC	Room	138,750	83,000	100,500	105,000	47,500	14	13.4	290
	10X	SRC	Room	116,000	87,000	101,000	106,000	65,000	2.5	2.3	295
	4Y	CRR	1200	86,600	------	67,000	71,000	40,000	13.5	19.5	---
	3Z	SRR	1200	89,375	------	69,500	73,500	37,500	15	23.2	---
	9X	STR	1200	89,875	------	68,000	73,000	30,000	14	18.6	---
	10Z	SRC	1200	88,000	------	70,000	73,500	35,000	7	12.0	---
H-4174-7A	4Y	(b) (c)	Room	112,500	56,500	74,000	81,000	37,500	20	27.2	223
	4X	(b) (c)	Room	112,625	68,000	78,000	83,500	47,500	23	29.2	223
	[d]1Y	(b) (c)	1200	-------	------	54,500	58,000	30,000	----	----	---
	1X	(b) (c)	1200	72,500	------	52,000	57,000	15,000	30	41.3	---
S1509	1X	SRR[c]	Room	122,000	71,000	88,500	94,500	42,500	19	22.7	248
	3X	STR[c]	Room	125,750	74,000	90,500	96,500	37,500	18	26.1	267
	1Y	SRR[c]	1200	81,100	------	62,600	65,900	33,700	24	36.6	---
	2X	SRR[c]	1200	79,000	------	62,000	65,000	37,500	24	32.8	---

[a]CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CTR center-plane tangential specimen near rim of disc.
STR surface-plane tangential specimen near rim of disc.
CRC center-plane radial specimen near center of disc.
SRC surface-plane radial specimen near center of disc.

[b]Specimens taken at a point midway between center and rim of this forging.

[c]The forgings were too thin to split into thirds. The specimens represent one-half of the thickness.

[d]Threads stripped before the specimen fractured.

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TABLE II

RUPTURE TEST RESULTS AT 1200° F FOR TIMKEN ALLOY DISCS

Disc	Specimen number	Specimen location (a)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
S451	6Y	CRR	50,000	41.5	16	22.5
	8Y	CRR	45,000	88	18	29.8
	8Y	CRR	40,000	382	12	16.7
	8Y	CRR	37,500	672	8	9.7
	8Y	CRR	35,000	775	10	17.2
	6Y	CRR	33,000	1182	11	21.2
	4Z	SRR	45,000	225	21	33.0
	9Y	CTR	45,000	114	22	27.7
	9Z	STR	45,000	237	17	31.9
	8Y-C	CRC	45,000	112.5	12	10.9
C0713	3Y	CRR	45,000	70	7	12.1
	3Y	CRR	40,000	188	8	13.8
	3Y	CRR	35,000	464	[b]9	8.5
	3Y	CRR	32,500	785	5	6.2
	1Y	CRR	30,000	1295.5	5	6.8
	4Z	SRR	43,000	159	18.5	23.3
	9Y	CTR	43,000	172	15	28.8
	9X	STR	43,000	181	19	22.3
	8Y-C	CRC	43,000	133	8	9.7
C3B-441	3Y	CRR	50,000	29	[b]1	2.8
	1Y	CRR	45,000	76.5	3	3.3
	3Y	CRR	42,000	292	[b]1	2.3
	1Y	CRR	40,000	434.5	3	2.3
	1Y	CRR	35,000	772	2	2.3
	1Y	CRR	33,000	807	3	2.3
	3Y	CRR	31,000	2401	6	3.7
	4Z	SRR	44,000	168	2	3.7
	9Y	CTR	44,000	204	4	2.3
	9X	STR	44,000	126	4	3.7
	10Y	CRC	44,000	140	[b]3	3.0
H-4174-7A	2Y	(c)	45,000	60	29	34.0
	2Y	(c)	40,000	155	26	27.2
	2Y	(c)	35,000	424	22	26.7
S1509	4Y	SRR	55,000	50	21	30.8
	4Y	SRR	50,000	112	30	36.9
	4Y	SRR	45,000	148	32	40.8
	4Y	SRR	40,000	373	33	38.8
	4Y	SRR	35,000	715	29	36.0
	3Y	STR	50,000	84	[b]28	30.8

[a]CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CTR center-plane tangential specimen near rim of disc.
STR surface-plane tangential specimen near rim of disc.
CRC center-plane radial specimen near center of disc.

[b]Broke in gage mark.

[c]Specimens taken at a point midway between center and rim of this forging.

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TABLE III

RUPTURE TEST CHARACTERISTICS AT 1200° F OF TIMKEN ALLOY DISCS

Disc	Stress (psi) for rupture in -				Estimated elongation (percent) to rupture in-			
	10 hr	100 hr	1000 hr	2000 hr	10 hr	100 hr	1000 hr	2000 hr
S451	[a]56,000	45,500	34,000	30,000	20	18	10	10
C0713	-------	44,000	31,000	28,000	--	7	5	5
C3B-441	56,000	44,000	34,000	31,500	1	2	3	6
H-4174-7A	-------	42,000	31,500	------	--	27	20	--
S1509	-------	49,000	34,000	------	--	30	30	--

[a]Obtained by extrapolation.

TABLE IV

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR TIMKEN ALLOY DISCS

Disc	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
8451	8Y	20,000	0.092	0.7	202	[a]1250	-----	----	----	----	----
	4Y	25,000	.115	---	77	590	-----	----	----	----	----
	6Y	30,000	.137	---	26	248	835	----	----	----	----
	6Y	33,000	.155	---	---	120	290	530	1060	580	2.2
	8Y	35,000	.16	---	---	2	25	205	650	360	2.8
	8Y	37,500	.17	---	---	100	190	370	----	370	2.0
	8Y	40,000	.185	---	---	15	60	150	320	150	2.0
	8Y	45,000	.21	---	---	-------	4	25	50	30	2.2
	6Y	50,000	.25	---	---	1.5	5	11	15	----	----
C0713	1Y	20,000	.096	---	70	568	-----	----	----	----	----
	1X	25,000	.128	---	18	224	966	----	----	----	----
	1Y	30,000	.14	---	4	50	180	520	----	1080	3.0
	3Y	32,500	.15	---	---	25	130	335	----	640	3.4
	3Y	35,000	.165	---	---	10	56	135	415	390	4.4
	3Y	40,000	.19	---	---	4	32	85	165	100	2.3
	3Y	45,000	.22	---	---	1	10	30	65	30	2.0
C3B-441	6Y	20,000	.095	---	82	-------	-----	----	----	----	----
	1X	25,000	.118	---	27	[a]1700	-----	----	----	----	----
	3Y	31,000	.15	---	---	500	2100	2200	----	----	----
	1Y	33,000	.16	---	---	25	70	550	----	----	----
	1Y	35,000	.165	---	---	30	80	770	----	----	----
	1Y	40,000	.19	---	---	15	60	415	----	----	----
	3Y	42,000	.20	---	---	27	100	----	----	----	----
	1Y	45,000	.22	---	---	-------	40	75	----	----	----
	3Y	50,000	.25	---	---	-------	49	----	----	----	----
H-4174-7A	6Y	20,000	.101	---	120	-------	-----	----	----	----	----
	3Y	25,000	.128	---	15	515	[a]1150	----	----	485	.48
	2Y	35,000	.18	---	---	8	38	100	250	70	1.5
	2Y	40,000	.215	---	---	-------	10	28	75	----	----
	2Y	45,000	.25	---	---	-------	-----	----	----	----	----
81509	4X	20,000	.104	---	60	[a]1225	-----	----	----	----	----
	2Y	25,000	.13	---	10	505	-----	----	----	740	.59
	4Y	35,000	.175	---	---	32	85	190	415	160	1.7
	4Y	40,000	.20	---	---	10	45	105	210	----	----
	4Y	45,000	.23	---	---	-------	14	35	83	----	----
	4Y	50,000	.27	---	---	-------	6	21	55	----	----
	4Y	55,000	.34	---	---	-------	-----	----	----	----	----

[a]Obtained by extrapolation of the creep curve.

TABLE V

TIME-DEFORMATION STRENGTHS AT 1200° F OF TIMKEN ALLOY DISCS

Disc	Total deformation (percent)	Stress (psi) to cause total deformation in -				
		1 hr	10 hr	100 hr	1000 hr	2000 hr
S451	0.1	[a]18,000	-------	-------	-------	-------
	.2	-------	35,000	23,500	12,500	-------
	.5	51,000	42,000	33,500	21,500	[a]17,500
	1.0	-------	46,800	37,500	28,700	-------
	Transition	-------	[a]50,500	41,500	30,100	-------
C0713	.2	[a]35,000	26,700	19,000	-------	-------
	.5	45,000	36,000	27,200	20,500	[a]15,700
	1.0	-------	43,700	34,000	24,600	[a]21,800
	Transition	-------	49,600	40,000	30,300	27,500
C3B-441	.2	-------	29,300	19,200	-------	-------
	.5	-------	[a]42,600	[a]34,600	[a]26,700	[a]24,300
	1.0	-------	-------	[a]41,200	[a]32,900	[a]30,300
	Transition	-------	-------	[a]45,000	[a]35,000	[a]32,000
H-4174-7A	.2	-------	26,000	20,400	-------	-------
	.5	[a]40,000	34,500	28,900	23,400	-------
	1.0	-------	40,000	32,600	25,500	[a]23,500
	Transition	-------	-------	33,000	21,500	-------
S1509	.2	-------	25,000	18,500	-------	-------
	.5	-------	40,000	30,900	21,600	[a]18,800
	1.0	-------	47,000	35,400	-------	-------
	Transition	-------	-------	38,000	23,000	-------

[a]Estimated.

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TABLE VI

CREEP TEST DATA AT 1200° F FOR TIMKEN ALLOY DISCS

Disc	Creep test conditions		Initial deformation (percent)	Total deformation (percent) at -			Creep rate (percent/hr) at -	
	Stress (psi)	Duration (hr)		100 hr	500 hr	1000 hr	500 hr	1000 hr
S451	20,000	1002	0.092	0.156	0.325	0.450	0.00036	0.000195
	25,000	1002	.115	.214	.457	.627	.00049	.00026
	30,000	1023	.137	.294	.766	1.085	.00086	.00052
C0713	20,000	1124	.096	.221	.470	.611	.00044	.00019
	25,000	1124	.128	.325	.769	1.011	.00075	.00034
C3B-441	20,000	1172	.095	.217	.344	.381	.000114	.000044
	25,000	1290	.118	.310	.432	.472	.000130	.00050
H-4174-7A	20,000	1002	.101	.195	.255	.323	.000136	.000129
	25,000	1002	.128	.286	.490	.822	.00049	.00076
S1509	20,000	1004	.104	.221	.330	.448	.000237	.000230
	25,000	1004	.130	.302	.497	.705	.00038	.00044

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TABLE VII

EFFECT OF CREEP TESTING AT 1200° F ON THE ROOM-TEMPERATURE PHYSICAL PROPERTIES OF TIMKEN ALLOY DISCS

Disc	Specimen number	Prior testing conditions		Residual room-temperature properties								
		Stress (psi)	Time (hr)	Tensile strength (psi)	Offset yield strength (psi) 0.02 percent	0.1 percent	0.2 percent	Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Izod impact strength (ft-lb)	Vickers hardness
S451	(a)	(b)	(b)	122,780	76,400	88,000	92,900	55,000	14	20	8, 8	[c]261-265 [d]247
	6Y	30,000	1023	-------	------	------	-------	------	----	----	2, 2	306
	4Y	25,000	1002	149,500	65,000	83,000	90,000	37,500	6.5	8.7	------	--------
C0713	(a)	(b)	(b)	121,160	76,750	88,800	94,250	50,000	17	25	8, 10	[c]242-252 [d]259
	1X	25,000	1124	-------	------	------	-------	------	----	----	3, 4	280
	1Y	20,000	1124	138,000	57,000	74,500	82,000	27,500	7.5	8.1	------	--------
C3B-441	(a)	(b)	(b)	135,750	81,000	94,700	100,100	55,000	20	24	8, 10	[c]254-267 [d]298
	1X	25,000	1290	-------	------	------	-------	------	----	----	4, 5	306
	6Y	20,000	1172	157,500	80,000	92,000	95,000	55,000	7	8.1	------	--------
H-4174-7A	(a)	(b)	(b)	112,550	62,250	76,000	82,250	42,500	22	28	12, 13	[e]242 [d]229
	3Y	25,000	1002	-------	------	------	-------	------	----	----	8, 9	233
	6Y	20,000	1002	109,500	47,000	62,000	69,000	20,000	16.5	20.4	------	--------
S1509	(a)	(b)	(b)	123,875	72,500	89,500	95,500	40,000	18	25	7, 9	[e]272-274 [d]216
	2Y	25,000	1004	-------	------	------	-------	------	----	----	6, 6	252
	4X	20,000	1004	119,000	62,000	76,500	82,000	45,000	11	13.7	------	--------

[a]Average of tests on center- and surface-plane specimens at rim of disc.

[b]Original condition.

[c]Center rim.

[d]Center.

[e]Rim.

TABLE VIII

COMPARATIVE PROPERTIES OF DISCS AND BAR STOCK OF TIMKEN ALLOY AND DISCS OF

19-9DL, CSA, AND LOW-CARBON N-155 ALLOYS

Type material	Heat number	Processing: Heat treatment: Temperature (°F)	Heat treatment: Time (hr)	Heat treatment: Cooling	Hot-cold-work: Temperature (°F)	Hot-cold-work: Reduction (percent)	Final treatment: Temperature (°F)	Final treatment: Time (hr)	Room-temperature physical properties: Tensile strength (psi)	Yield strength (psi): 0.02 percent	Yield strength (psi): 0.2 percent	Elongation (percent)	Brinell hardness	Rupture properties at 1200° F for - 100 hr: Strength (psi)	100 hr: Elongation (percent)	1000 hr: Strength (psi)	1000 hr: Elongation (percent)
Disc 8451	H-4315	(1)	(1)	(1)	(2)	(3)	1200	(4)	122,780	76,400	92,900	14	250-261	45,500	18	34,000	10
Disc C0713	13356	(1)	(1)	(1)	1250	21	1200	10	121,160	76,750	94,250	17	247-263	44,000	7	31,000	5
Disc 03B-441	13060	2150	2	W.Q.[5]	1250	(3)	1200	10	135,750	81,000	100,100	20	269-299	44,000	2	34,000	3
Disc H-4174-7A	H-4174	(1)	(1)	(1)	(2)	(3)	1200	(4)	112,550	62,250	82,250	22	223	42,000	27	31,500	20
Disc 81509	H-4684	(1)	(1)	(1)	1275	(3)	1200	(4)	123,875	72,500	95,500	18	248-267	49,000	30	34,000	30
Bar stock[6]	------	(7)	(7)	(7)	None	None	1200	1	137,750	94,750	111,500	19	279	52,000	28	39,000	18
Bar stock[8]	10446	(7)	(7)	(7)	None	None	----	---	141,500	83,500	106,000	25	298	44,000	26	34,000	14
Bar stock[8]	10446	2200	1	W.Q.	1200	10	----	---	136,500	84,300	109,400	28	269	46,000	2	43,000	2
Bar stock[8]	10446	2050	2	W.Q.	1200	5	----	---	121,750	69,000	85,500	34	248	47,000	13	38,000	17
Bar stock[8]	10446	2050	2	W.Q.	1200	10	----	---	146,750	92,000	122,650	24	291	50,000	28	40,000	15
Bar stock[8]	10446	2050	2	W.Q.	1200	20	----	---	156,100	110,000	133,000	18	334	53,000	7	42,000	9
Bar stock[8]	10446	2050	2	W.Q.	None	None	1400	24	115,625	39,500	53,500	23	224	41,000	40	30,000	--
19-9DL disc[9]	B10429	(1)	(1)	(1)	None	None	1200	(4)	103,250 to 107,750	38,000 to 46,500	54,000 to 62,000	19 to 34.5	202 to 208	40,000	27	34,000	16
CSA disc[10]	1X2218	(1)	(1)	(1)	None	None	1200	4	106,500 to 113,300	37,000 to 46,000	56,000 to 69,500	33 to 38	204 to 227	35,500	32	30,000	18
Low-carbon N-155 disc[11]	A11534	(1)	(1)	(1)	None	None	1200	2	118,290	58,750	72,650	35	211 to 255	55,000	12	42,000	10

[1]Hot-forged.
[2]Hot-cold-working temperature was presumably between 1200° and 1300° F.
[3]Amount of hot-cold-work not known.
[4]Time of stress relief not known.
[5]W.Q., water-quenched.
[6]See reference 5.
[7]Hot-rolled.
[8]Unpublished data from the University of Michigan.
[9]See reference 1.
[10]See reference 2.
[11]See reference 3.

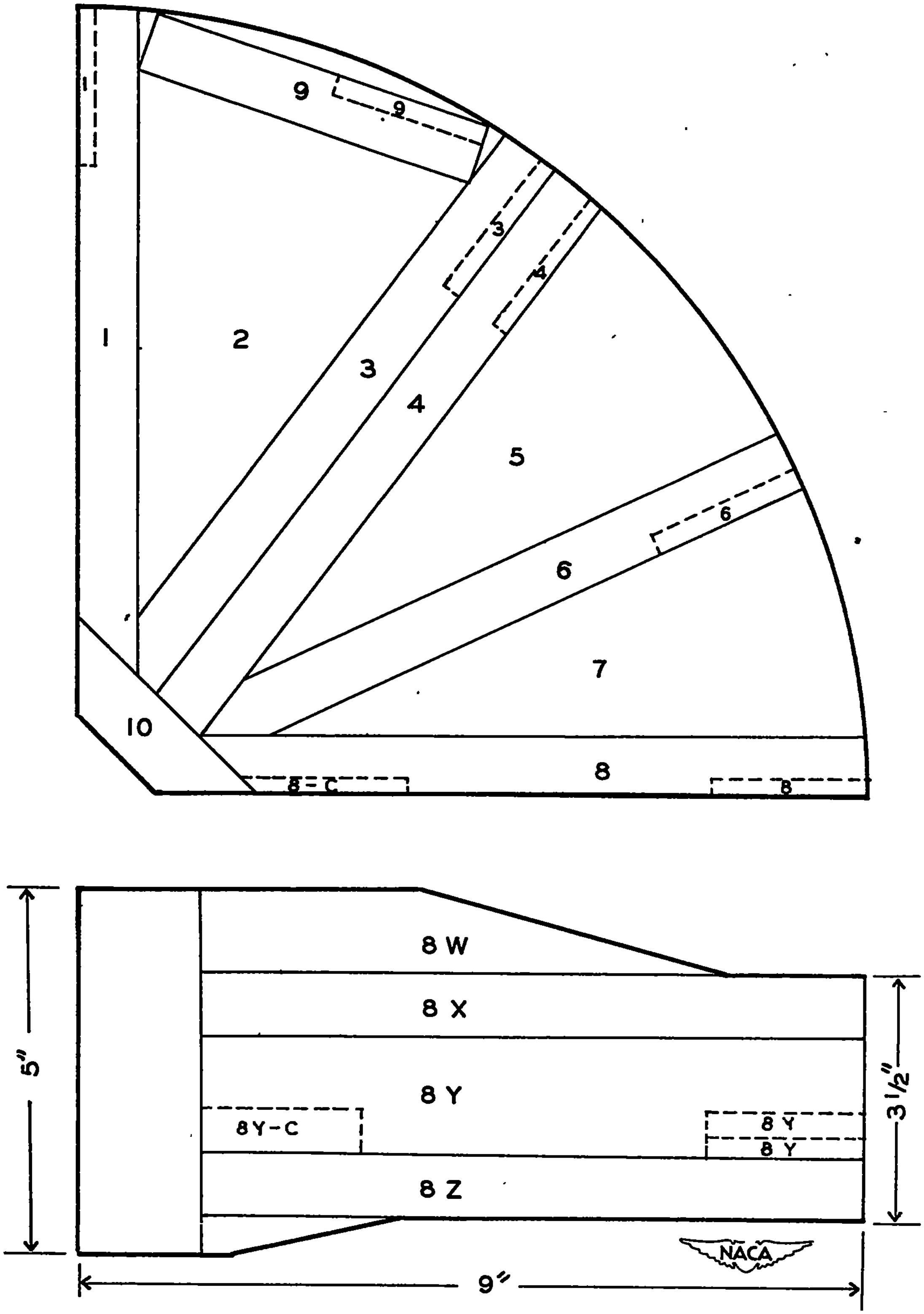
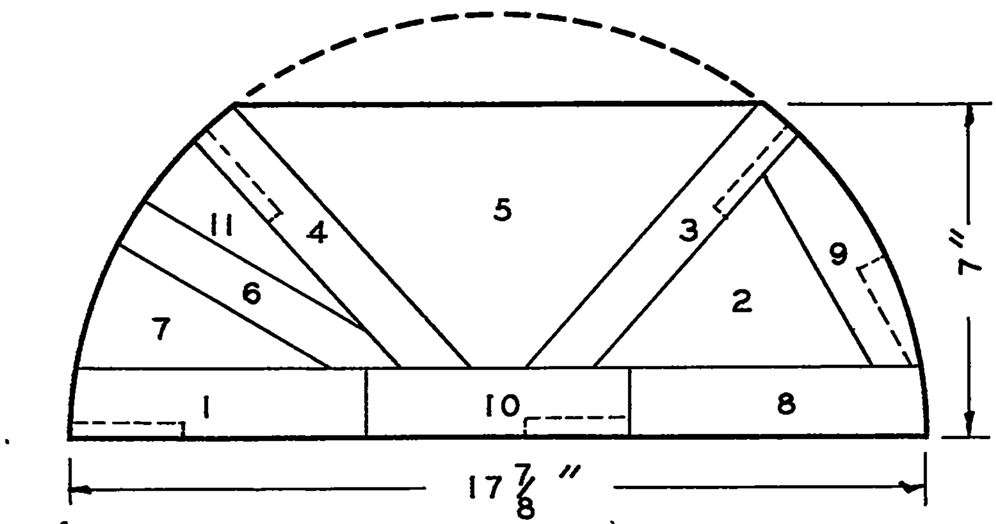


Figure 1.– Location of test coupons in quarter sections of discs S451 and C0713 of Timken alloy.



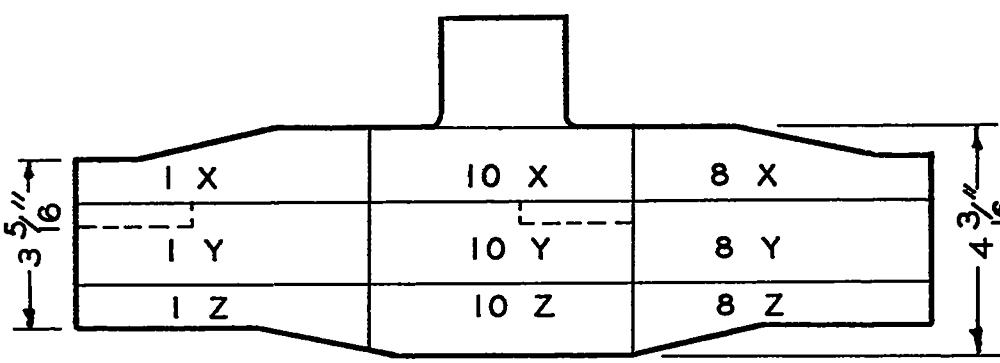


Figure 2.– Location of test coupons in half section of disc C3B-441 of Timken alloy.

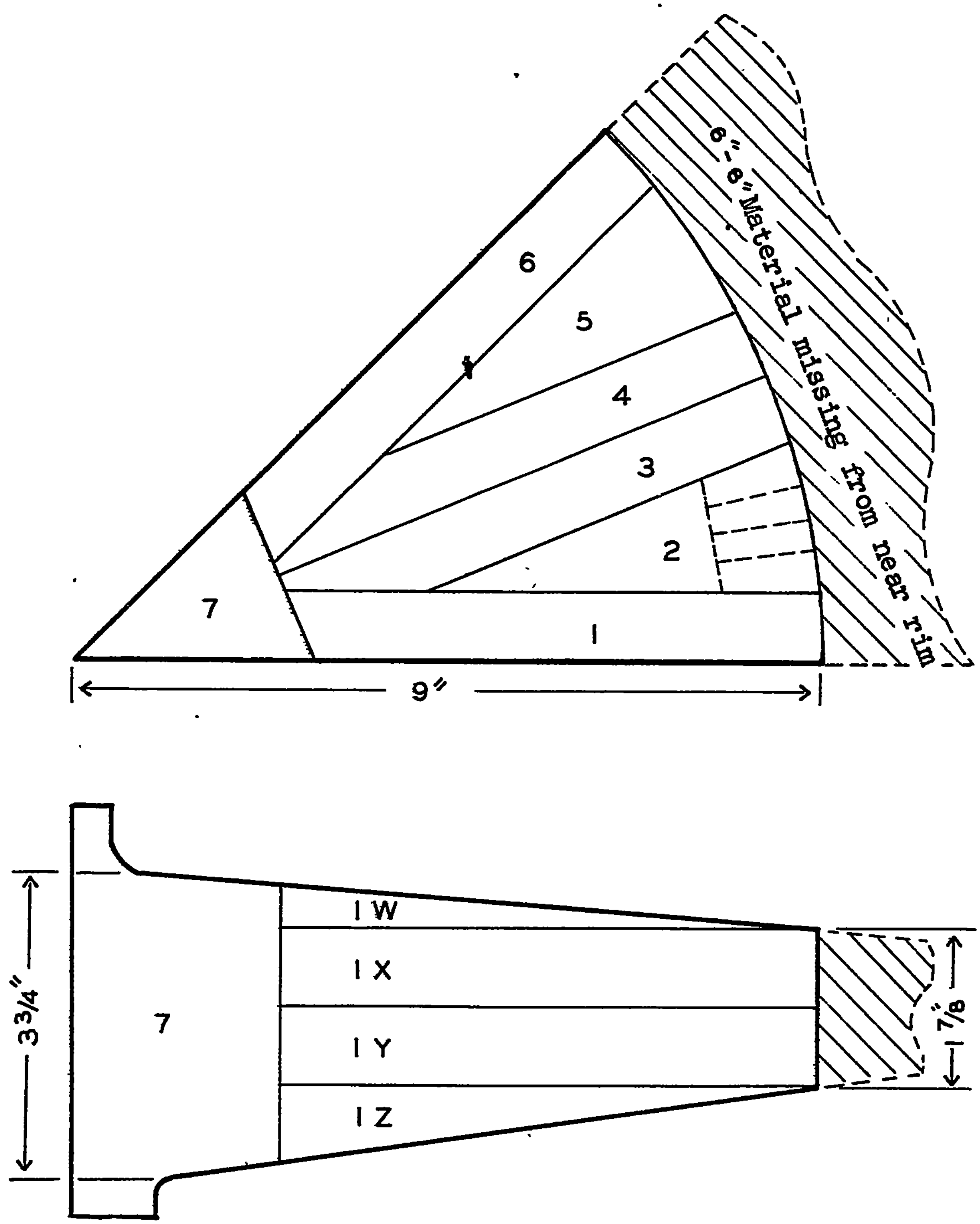
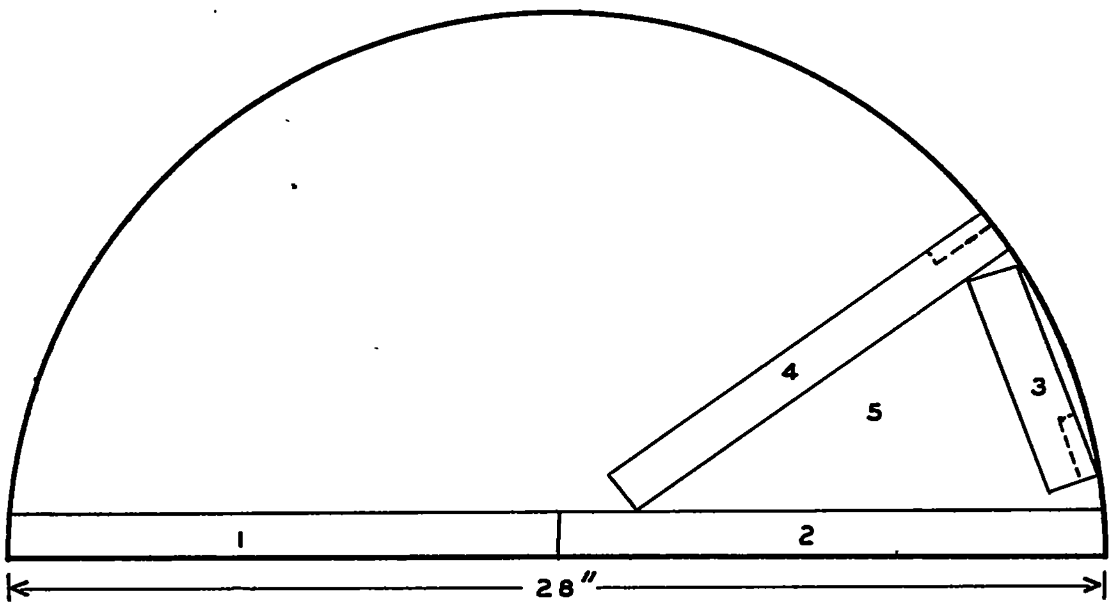


Figure 3.– Location of test coupons in eighth section of disc H-4174-7A of Timken alloy.



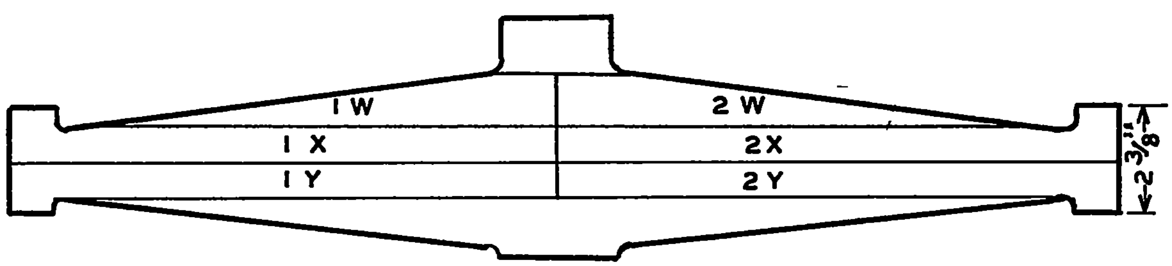
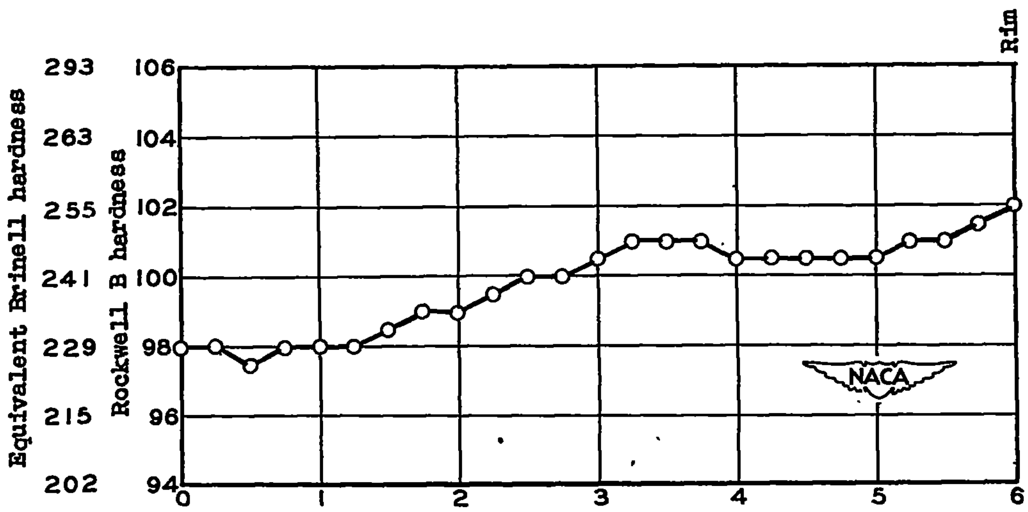
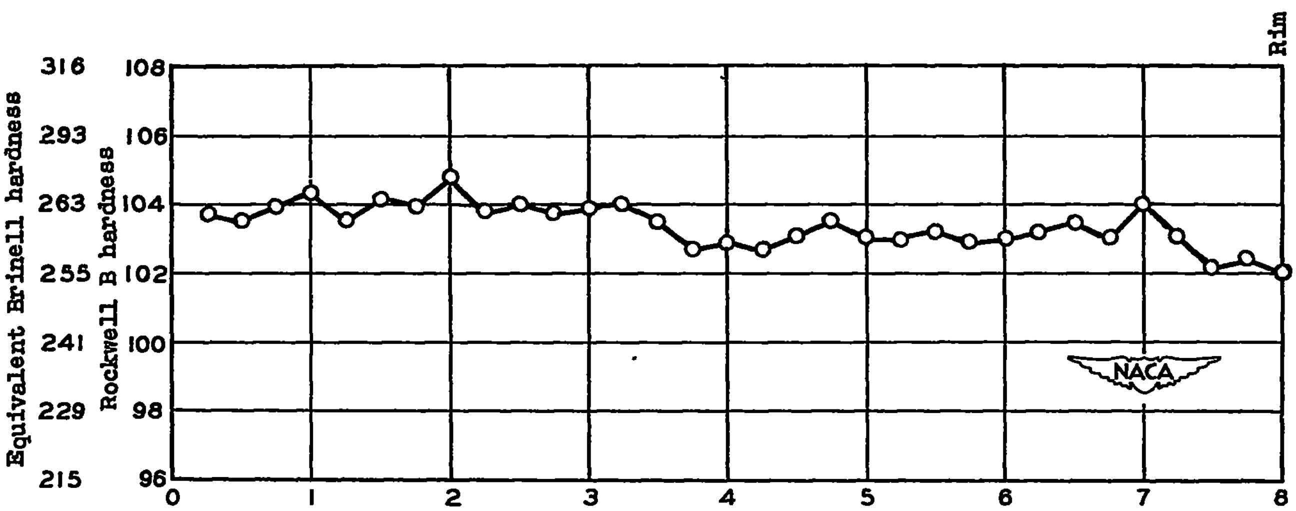


Figure 4.– Location of test coupons in half section of disc S1509 of Timken alloy.



In. from center end to rim end of test coupon 6Z
(0—surface next to Y— or center plane)

Figure 5.— Variation in hardness from center to rim of disc S451 of Timken alloy.



In. from center end to rim end of test coupon 6X
(0—surface next to Y— or center plane)

Figure 6.— Variation in hardness from center to rim of disc C0713 of Timken alloy.

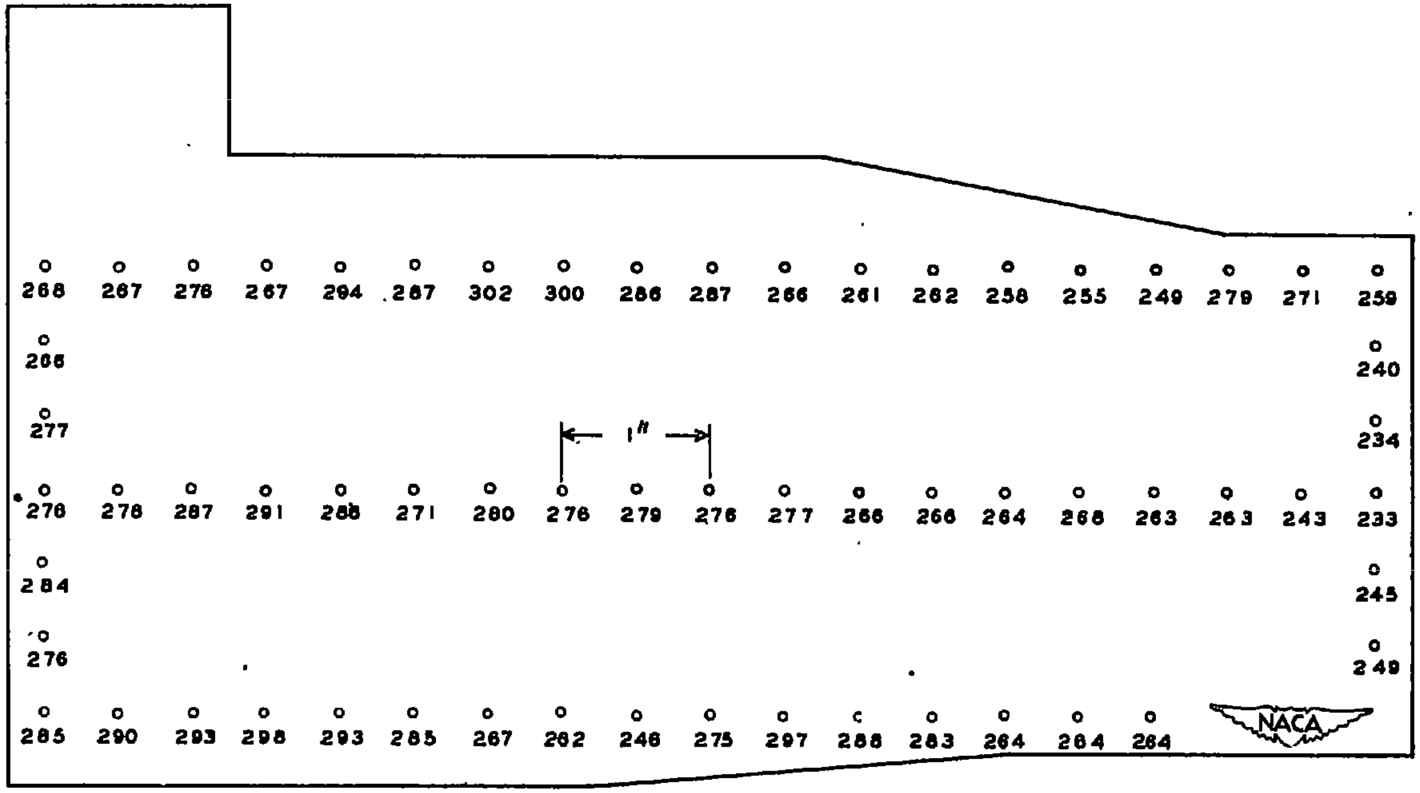


Figure 7.– Hardness survey on half section of disc 03B-441 of Timken alloy. Brinell hardness; disc sections 8 and 10.

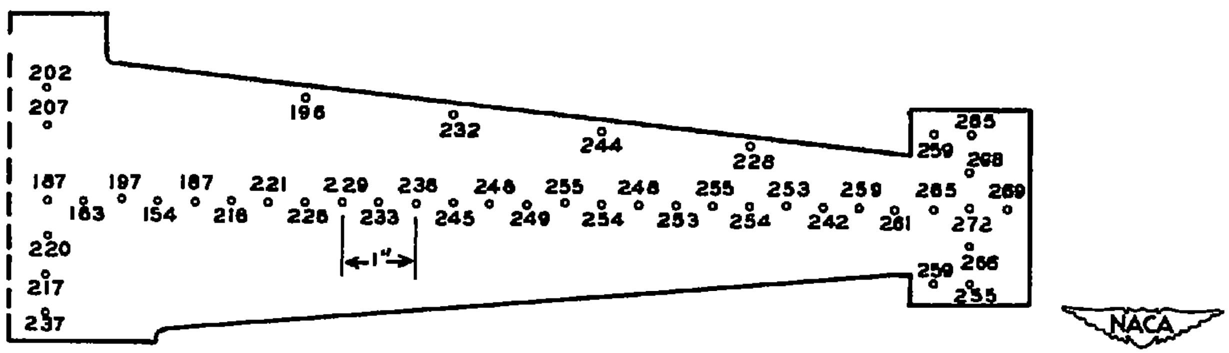


Figure 8.– Hardness survey on half section of disc S1509 of Timken alloy. Brinell hardness; disc section 2.

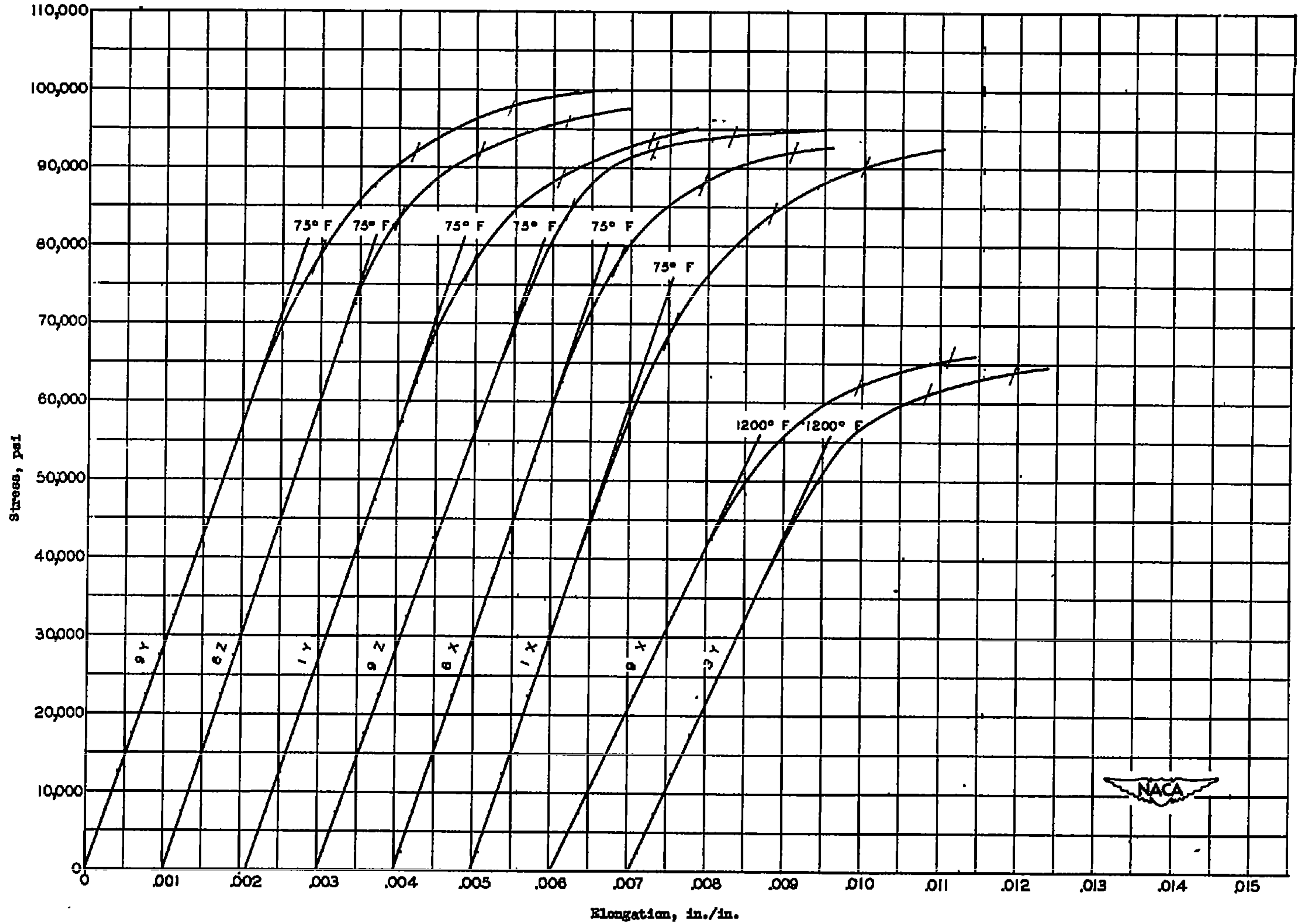


Figure 9.- Stress-strain curves for short-time tensile tests of disc S451 of Timken alloy.

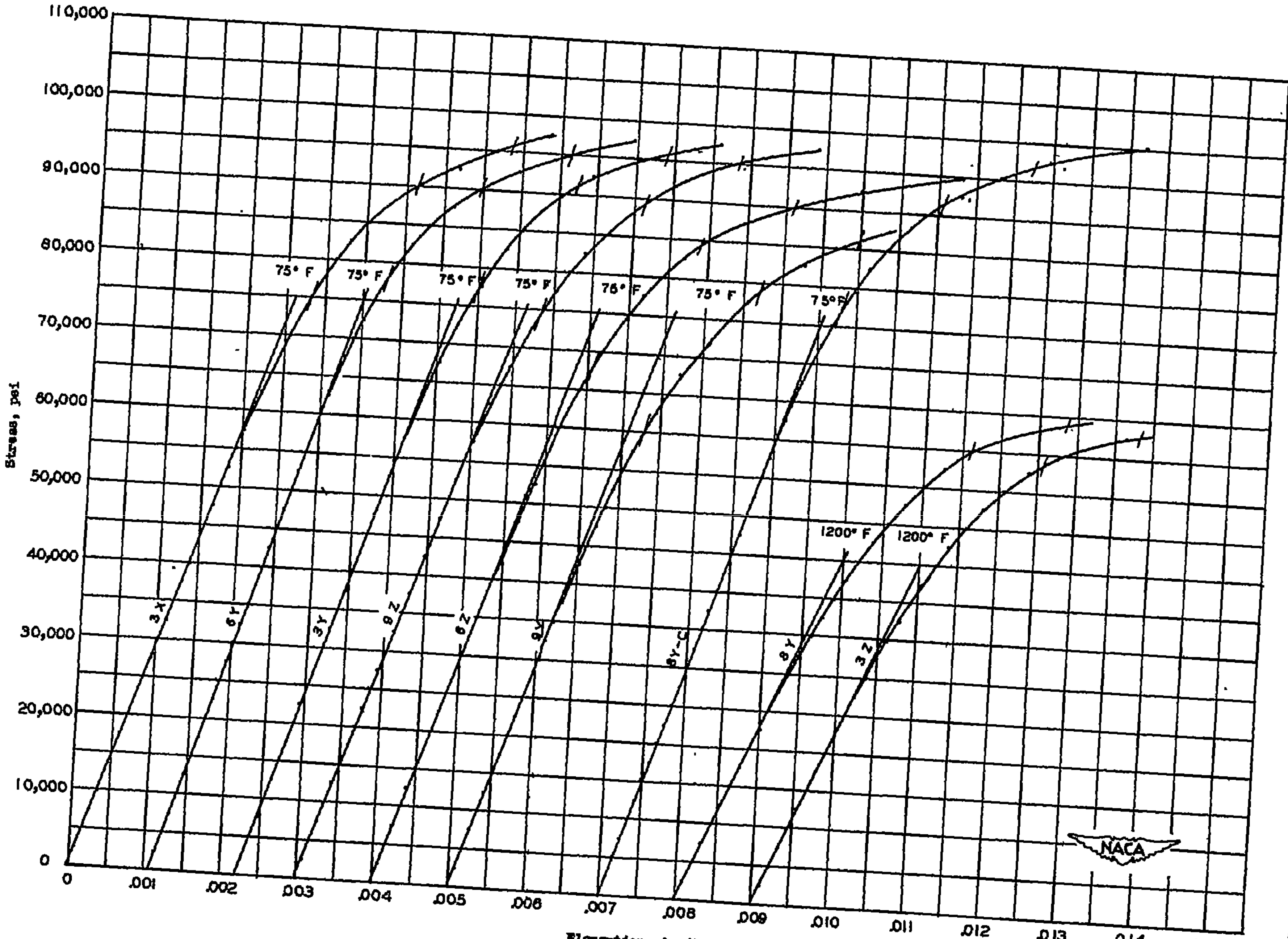


Figure 10.- Stress-strain curves for short-time tensile tests of disc C0713 of Timken alloy.

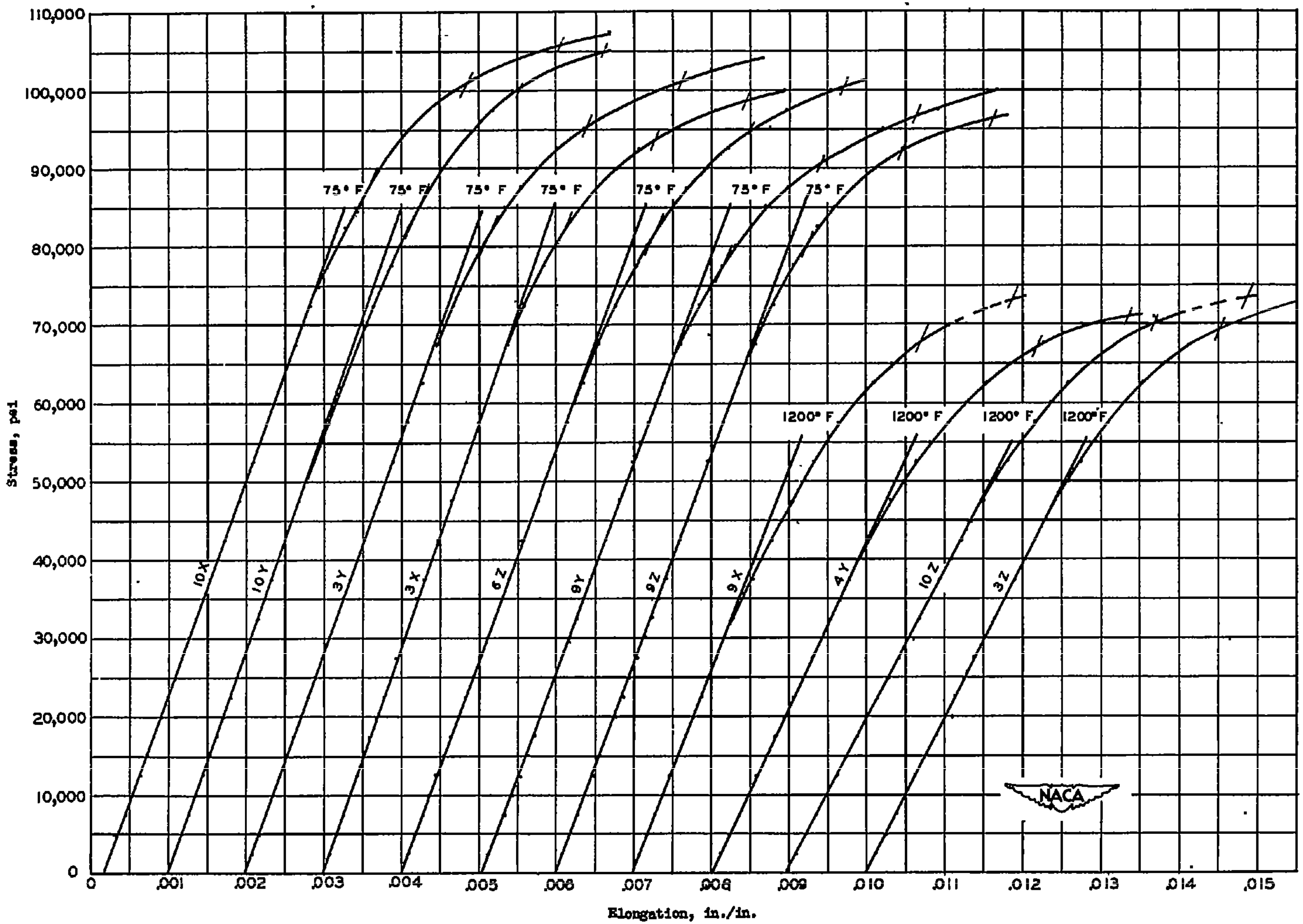


Figure 11.- Stress-strain curves for short-time tensile tests of disc 03B-441 of Timken alloy.

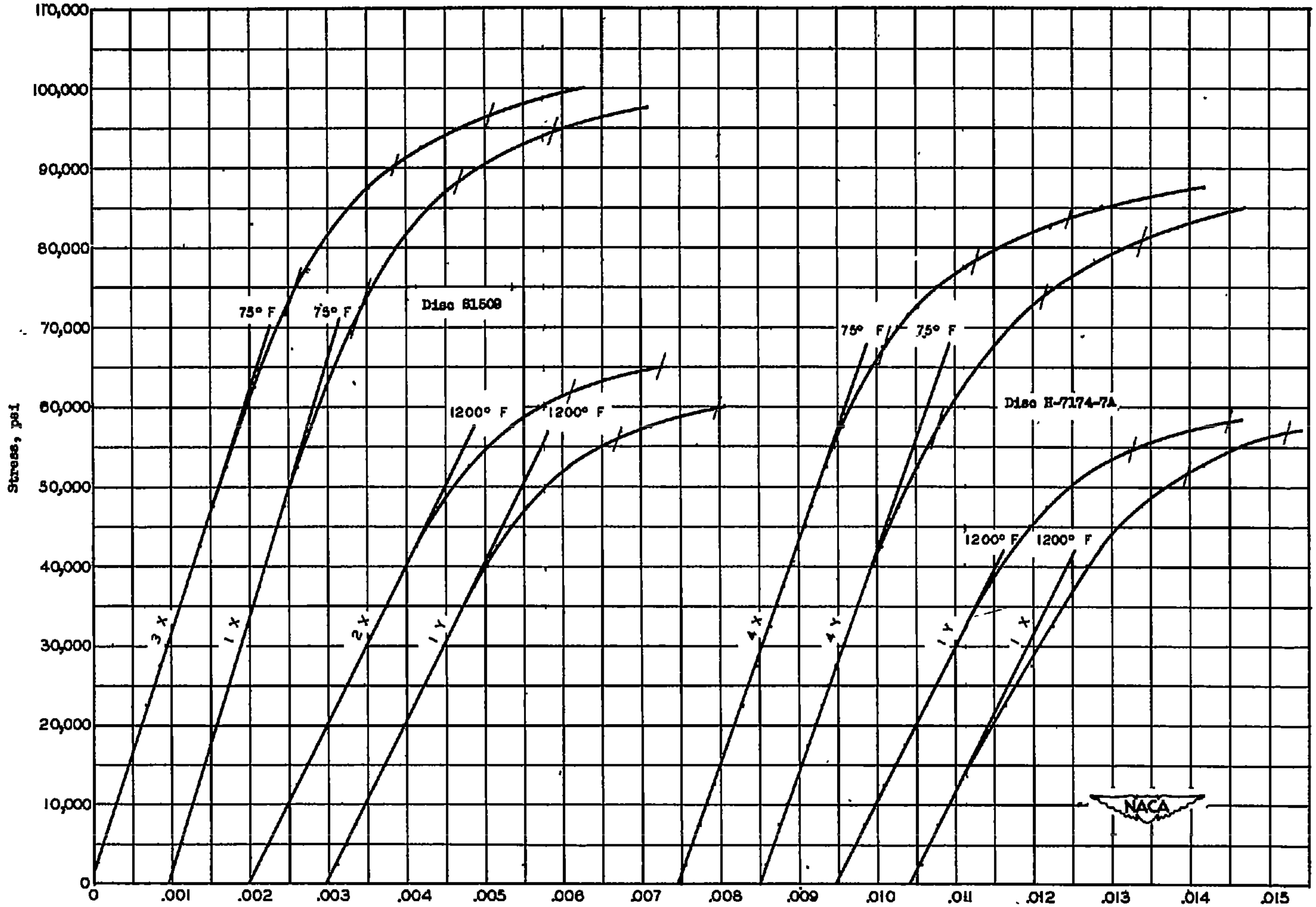
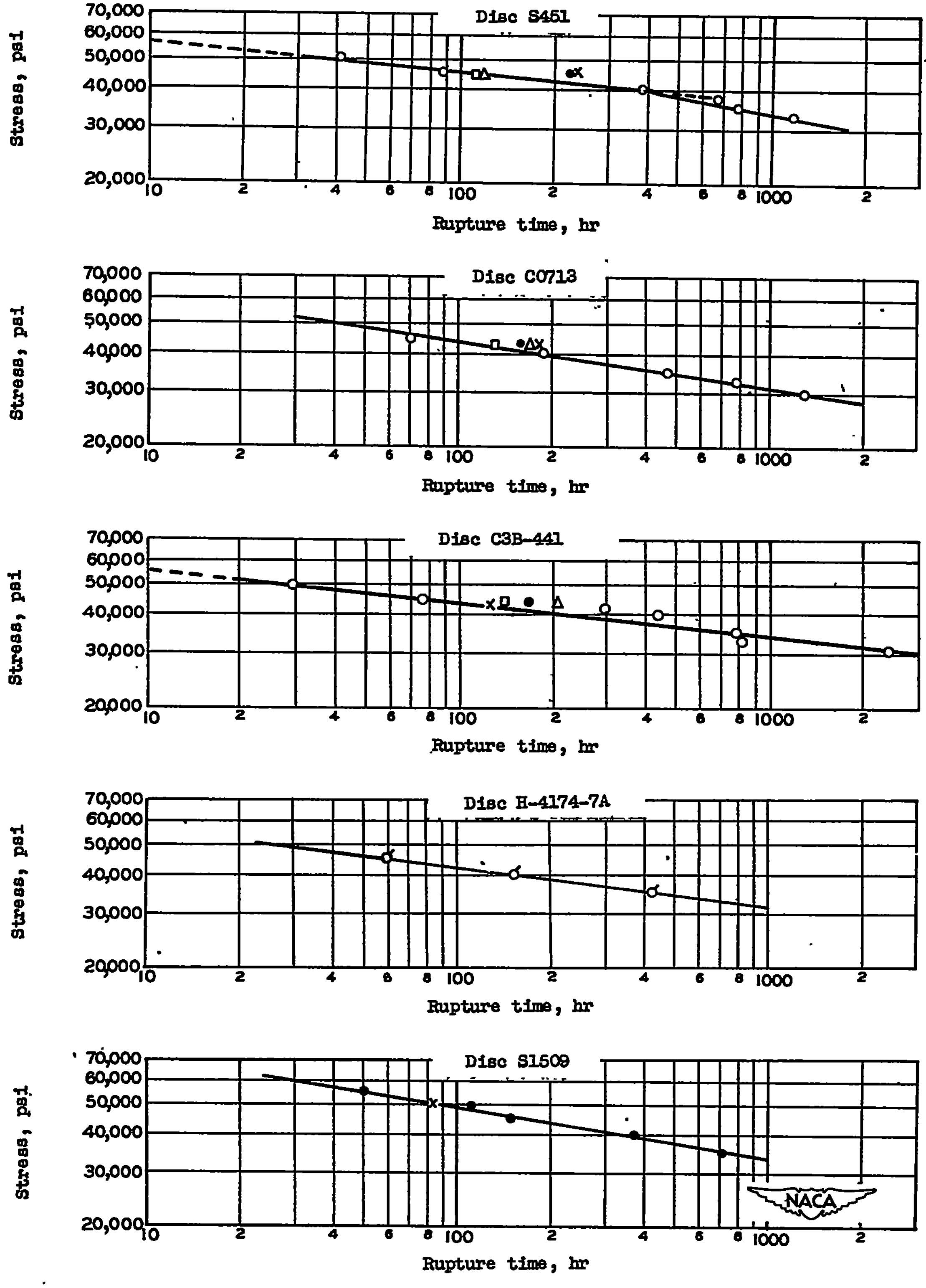


Figure 12.- Stress-strain curves for short-time tensile tests of discs S1509 and H-7174-7A of Timken alloy.



Location of specimen in disc

- O Center radial specimen near rim
- ● Surface radial specimen near rim
- Δ Center tangential specimen near rim
- × Surface tangential specimen near rim
- □ Center radial specimen near center
- ơ Specimen taken midway between center and rim

Figure 13.– Curves of stress against rupture time at 1200° F for Timken alloy discs.

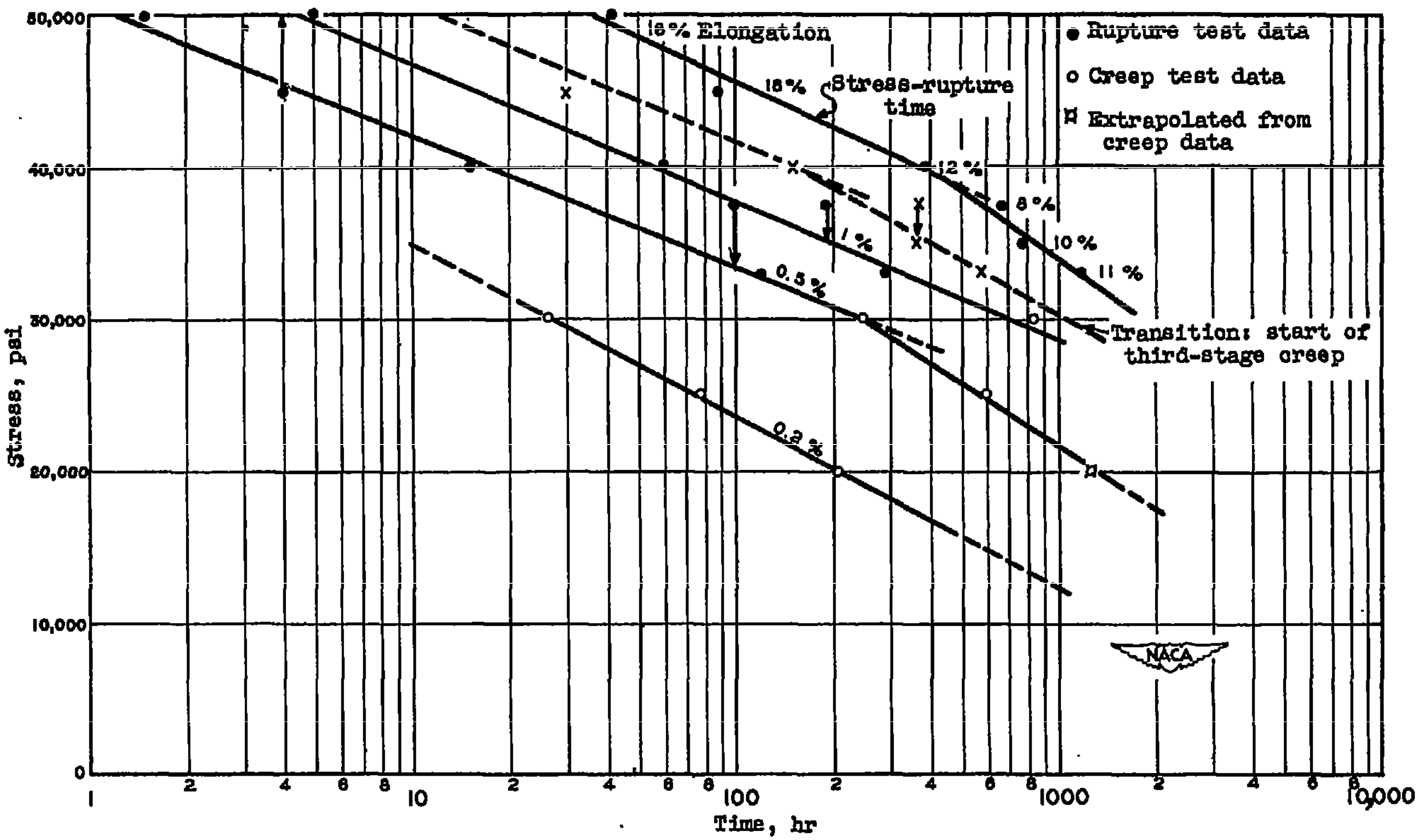


Figure 14.– Curves of stress against time for total deformation at 1200° F for disc S451 of Timken alloy.

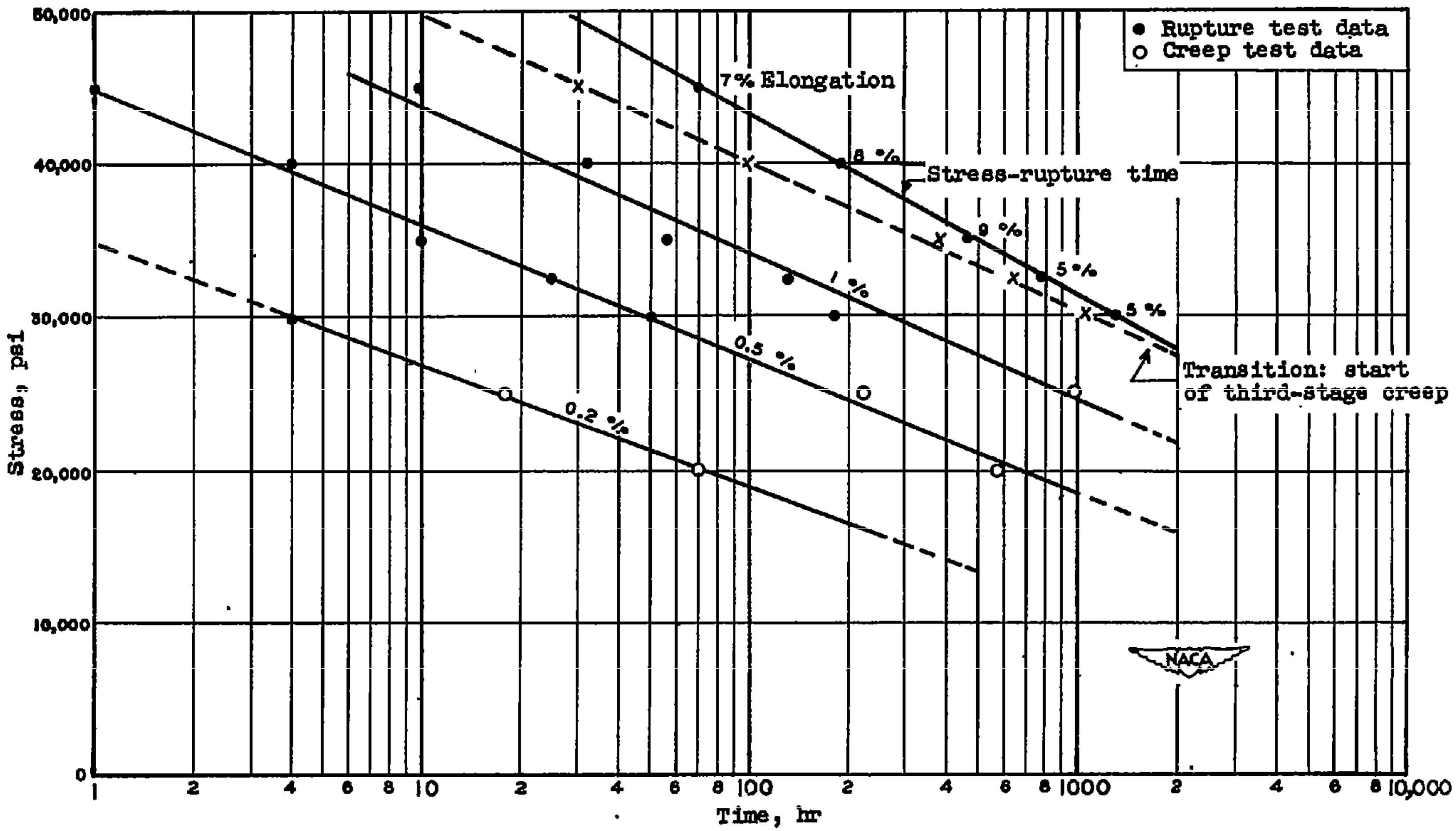


Figure 15.– Curves of stress against time for total deformation at 1200° F for disc C0713 of Timken alloy.

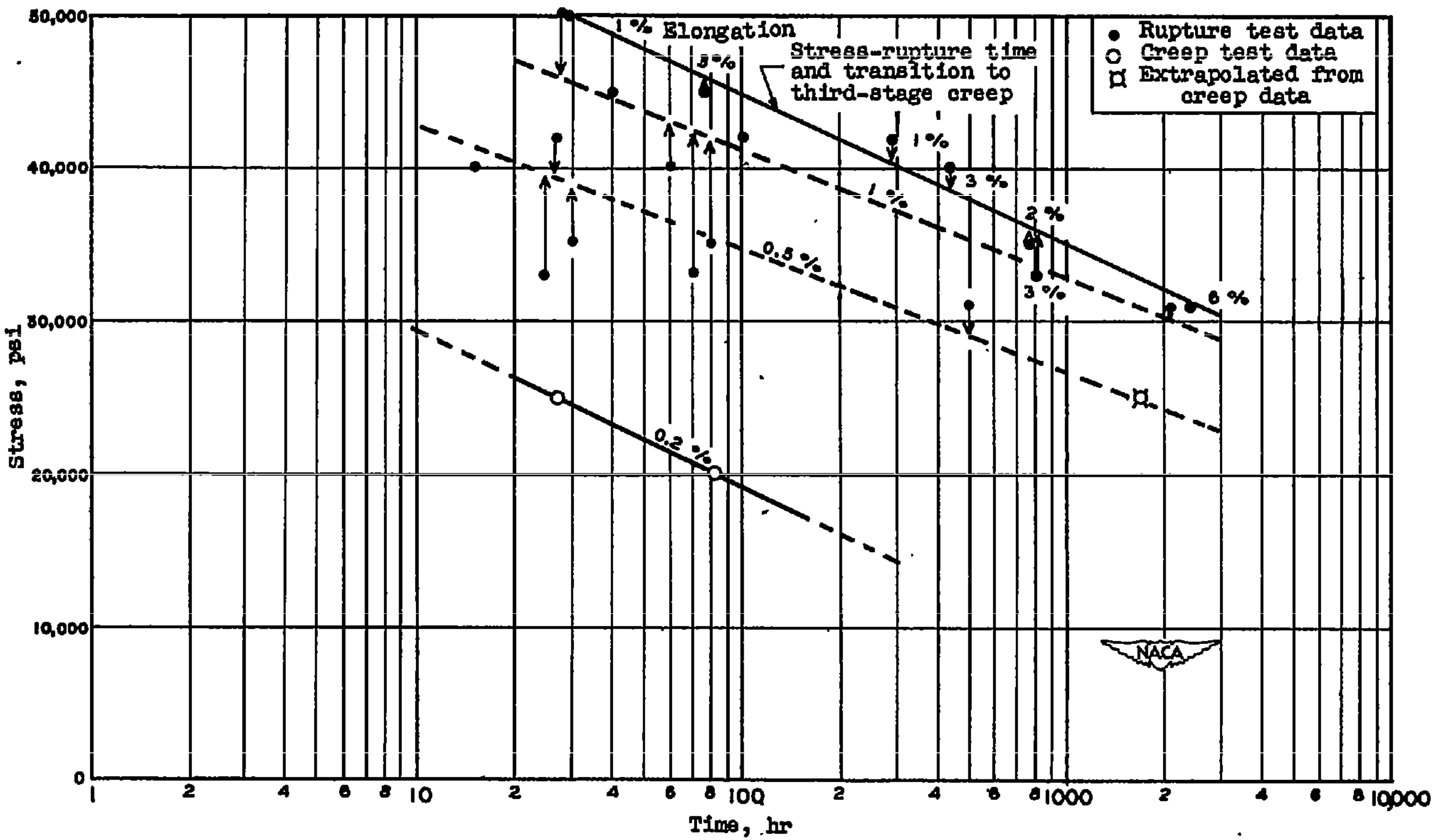


Figure 16.– Curves of stress against time for total deformation at 1200° F for disc C3B-441 of Timken alloy.

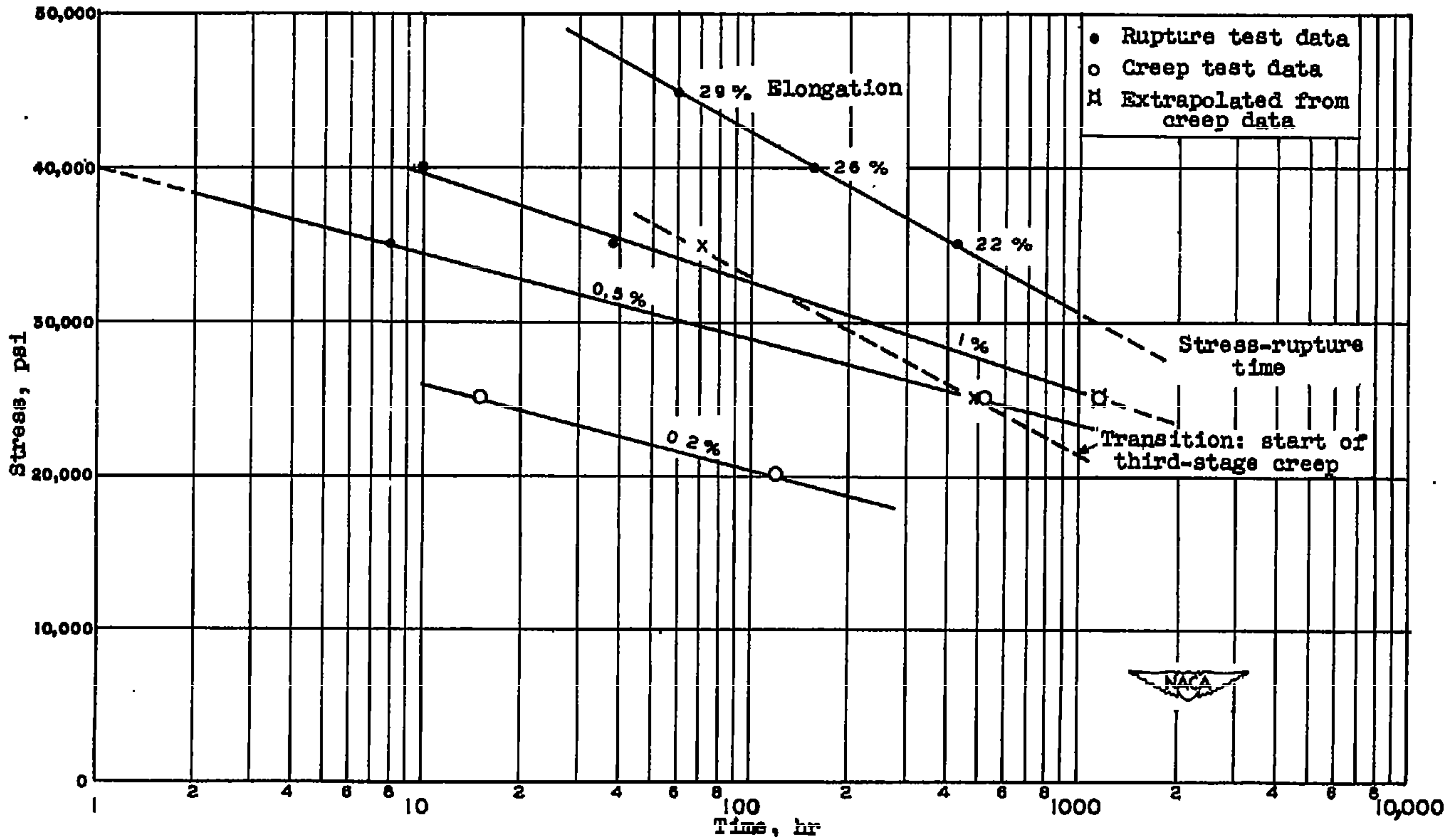


Figure 17.– Curves of stress against time for total deformation at 1200° F for disc H-4174-7A of Timken alloy.

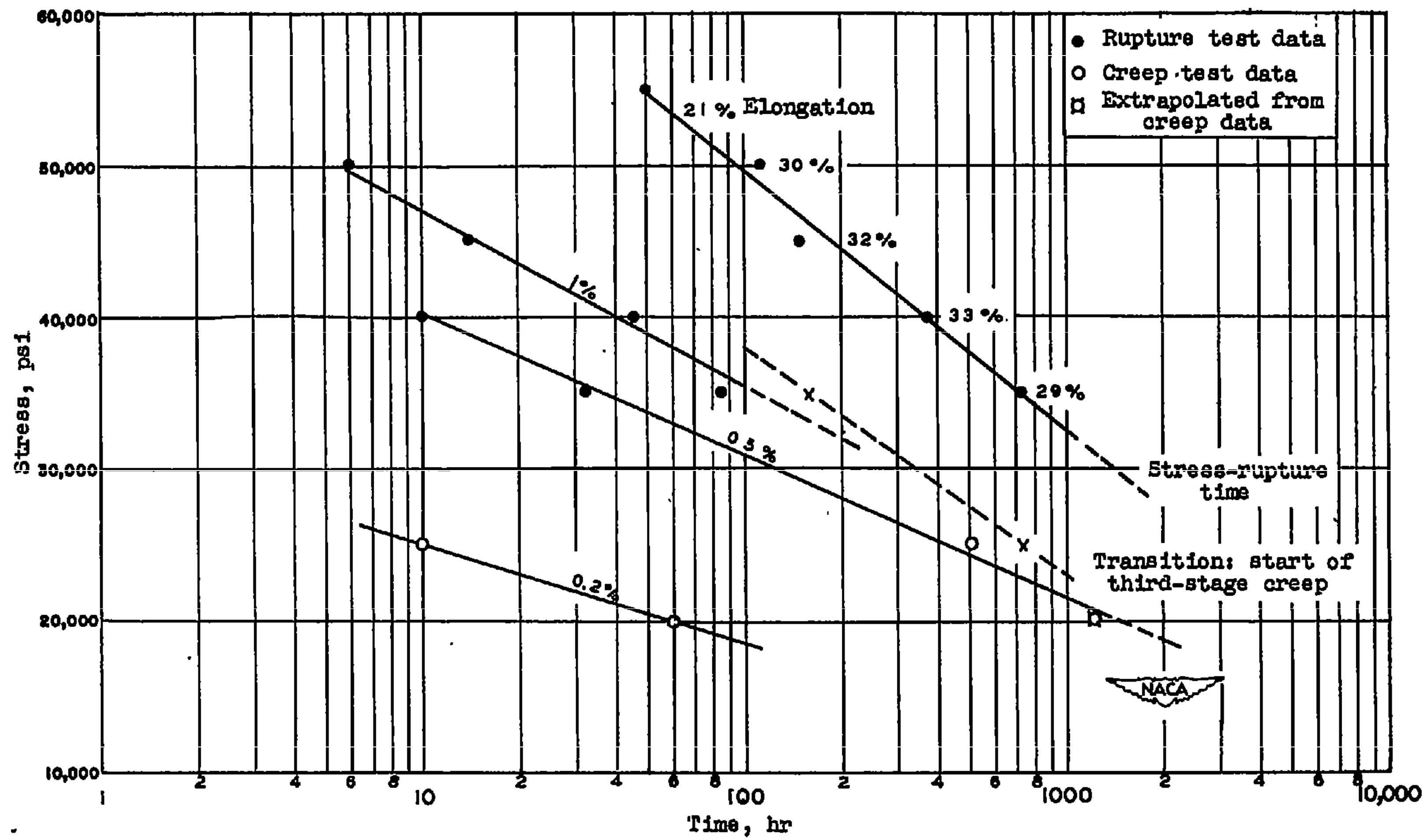


Figure 18.– Curves of stress against time for total deformation at 1200° F for disc S1509 of Timken alloy.

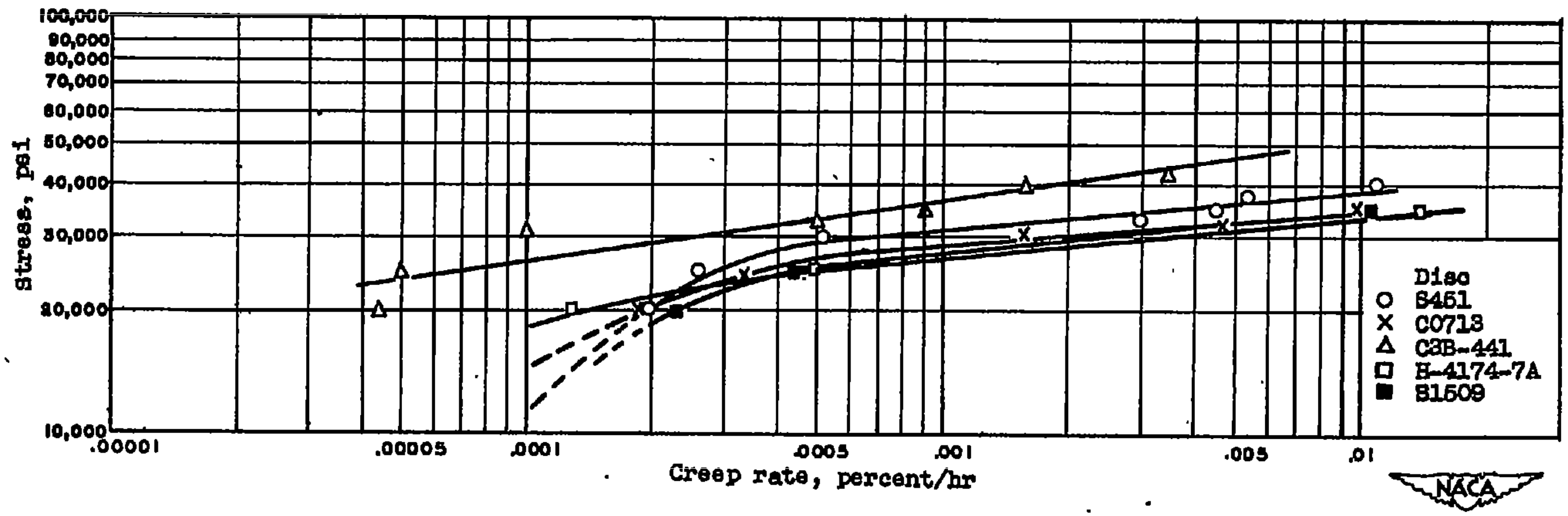
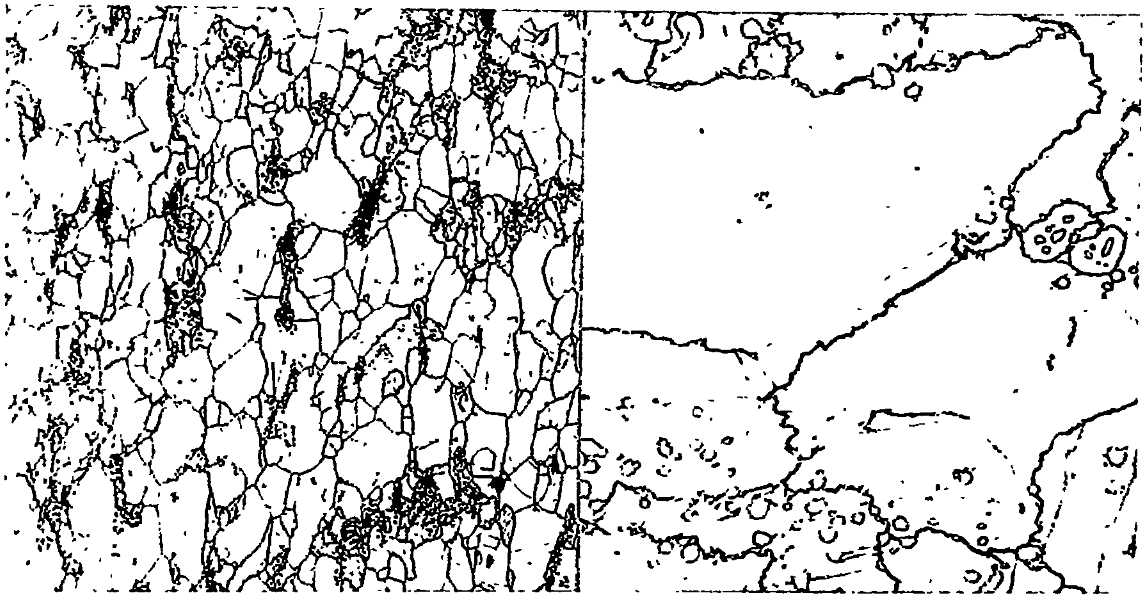
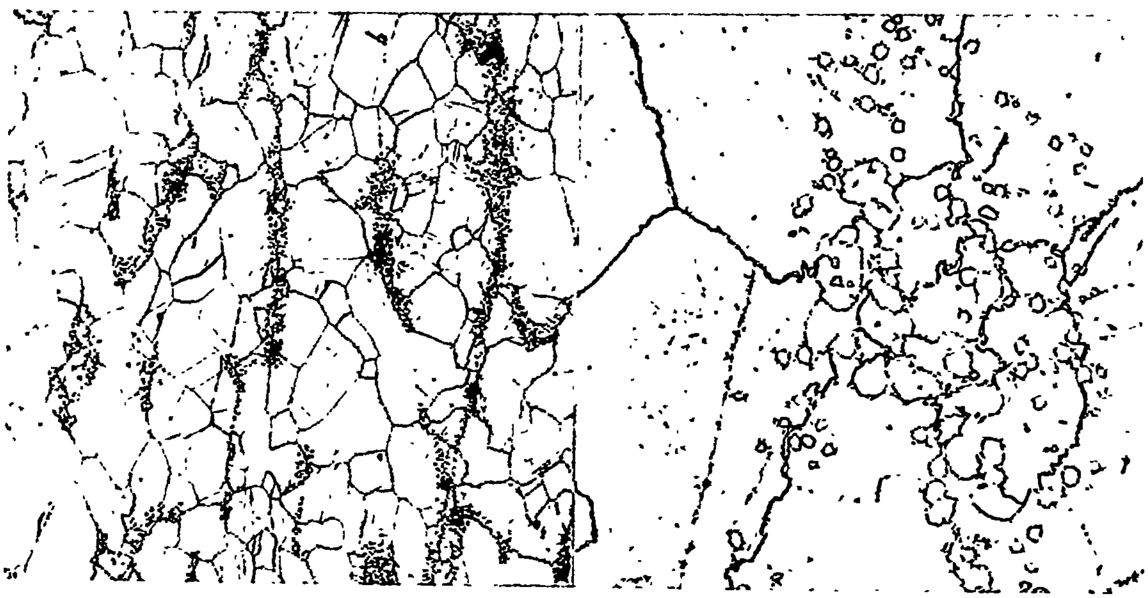


Figure 19.– Curves of stress against creep rate at 1200° F for Timken alloy discs. All data at stresses above 30,000 psi from rupture tests.



100X 1000X

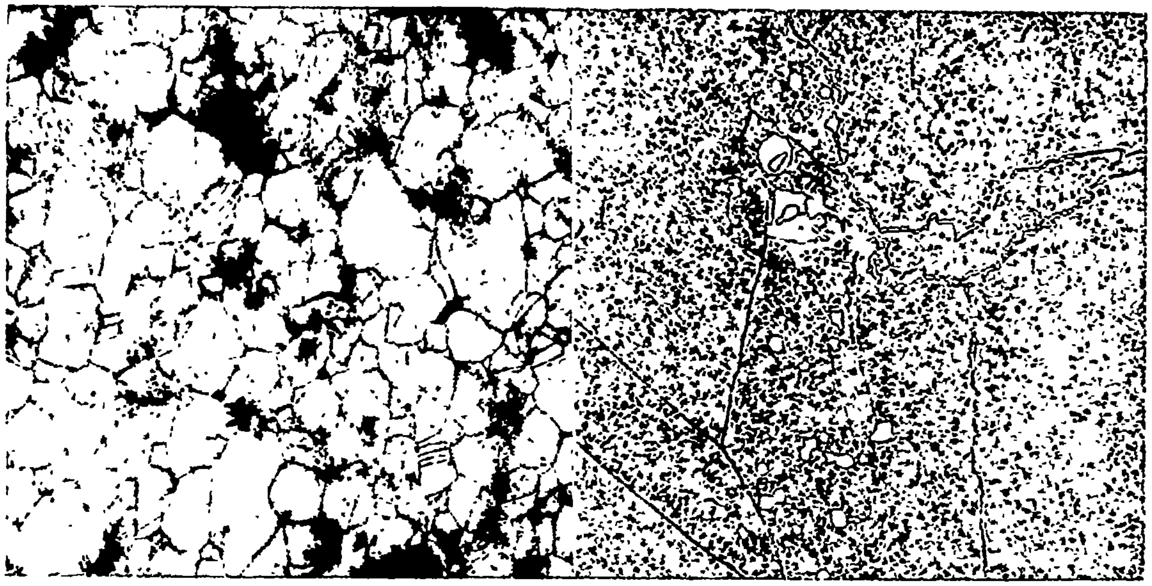
(a) Radial section near rim of disc in Y–plane.



100X 1000X

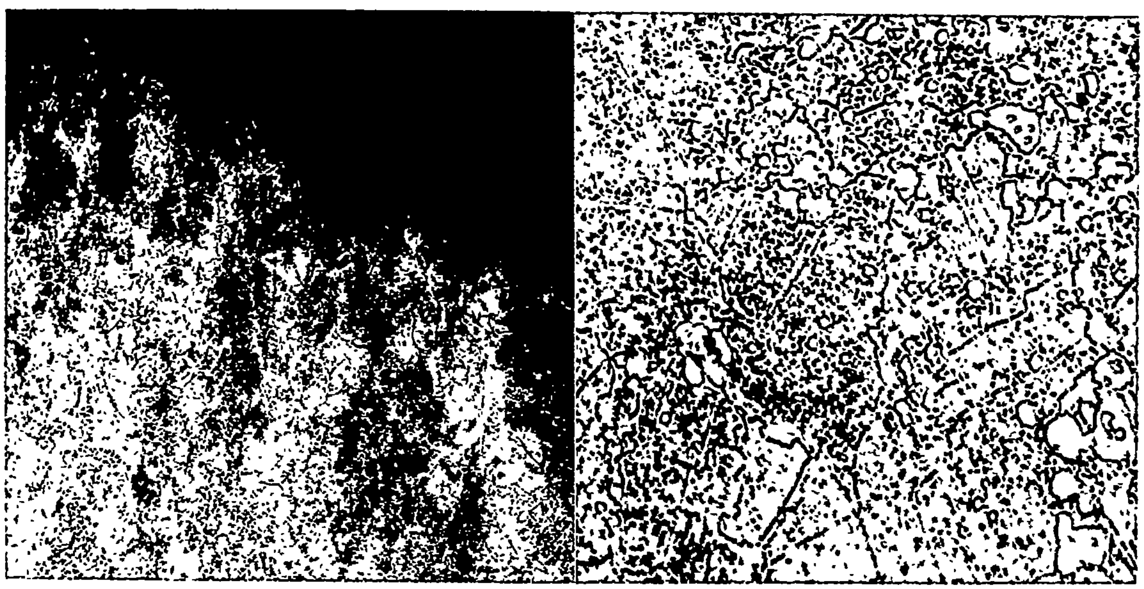
(b) Radial section near center of disc in Y–plane.

Figure 20.– Original microstructure of disc S451 of Timken alloy.



100X 1000X

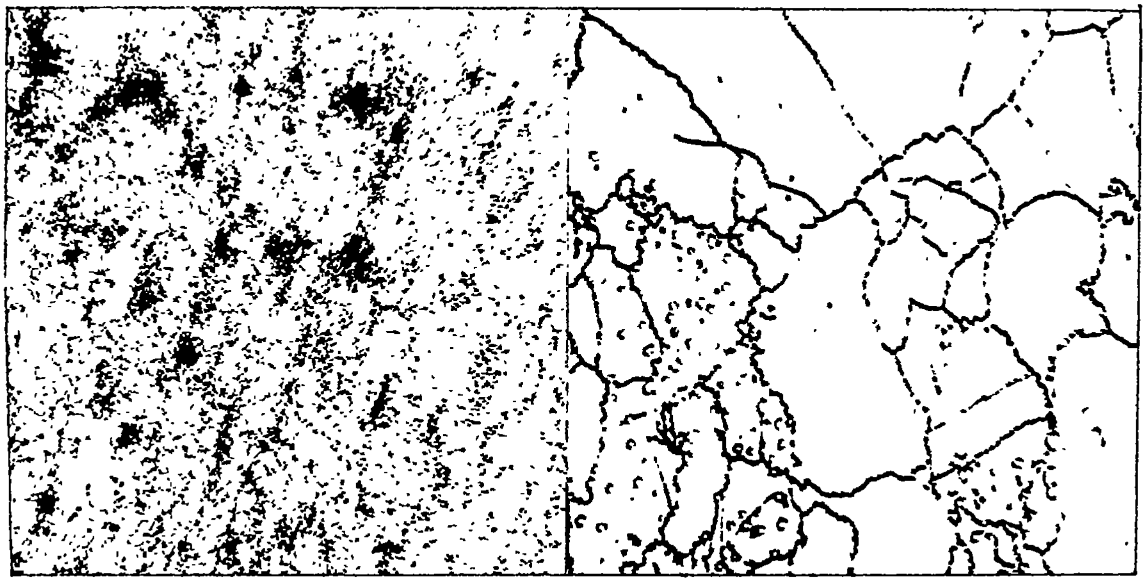
(a) Creep specimen 6Y; 1023 hours under 30,000 psi.



Fracture – 100X Interior – 1000X

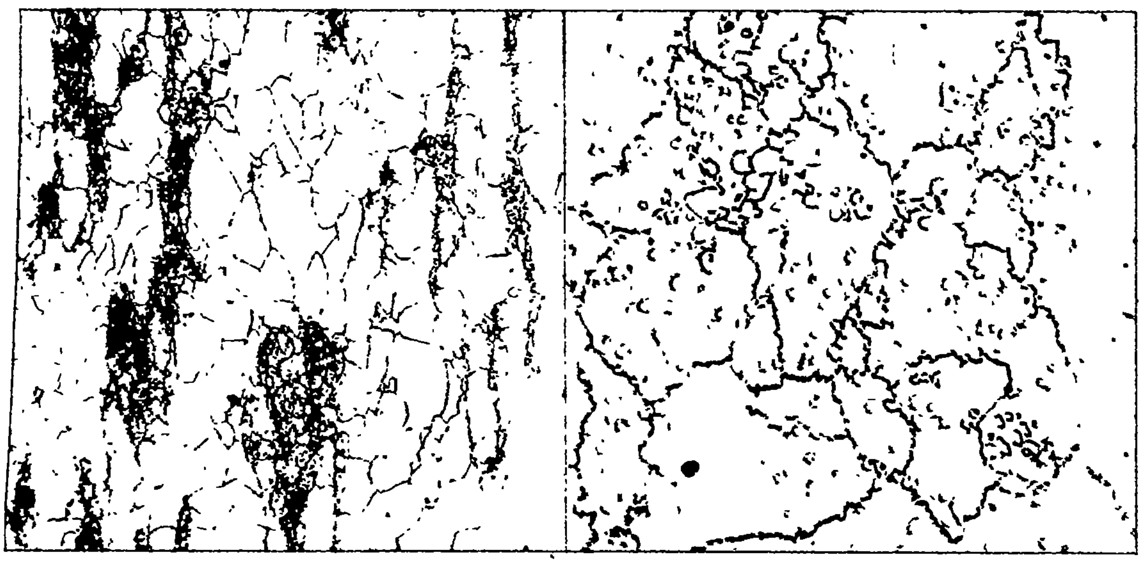
(b) Rupture specimen 6Y; 1182 hours for rupture under 33,000 psi.

Figure 21.– Microstructures of completed 1200° F creep- and rupture-test specimens from disc S451 of Timken alloy.



100X 1000X

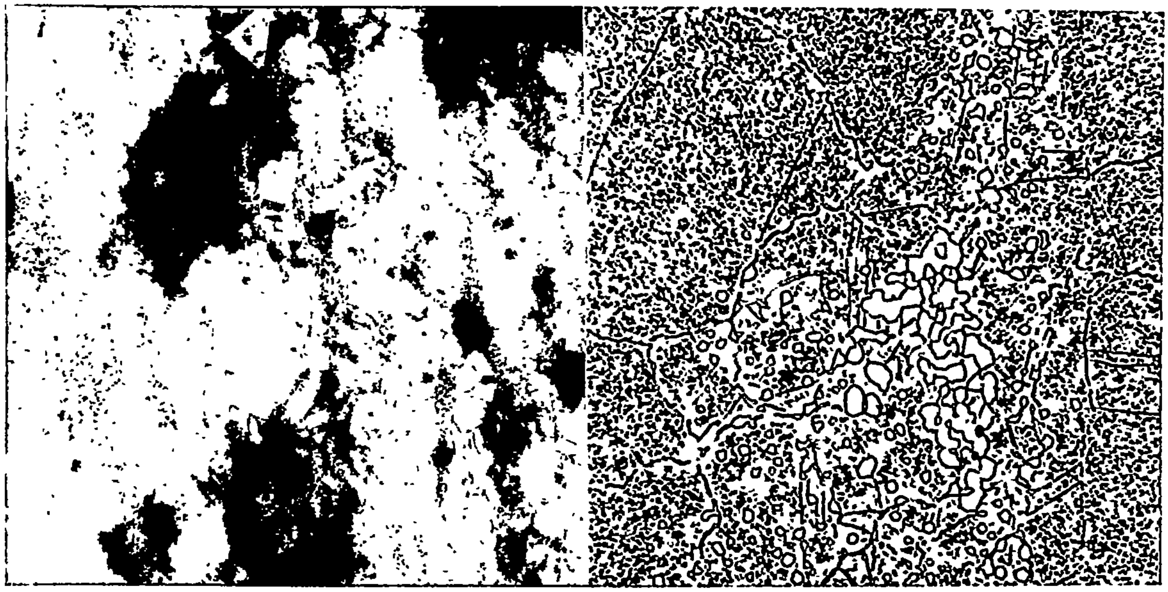
(a) Radial section near rim of disc in Y-plane.



100X 1000X

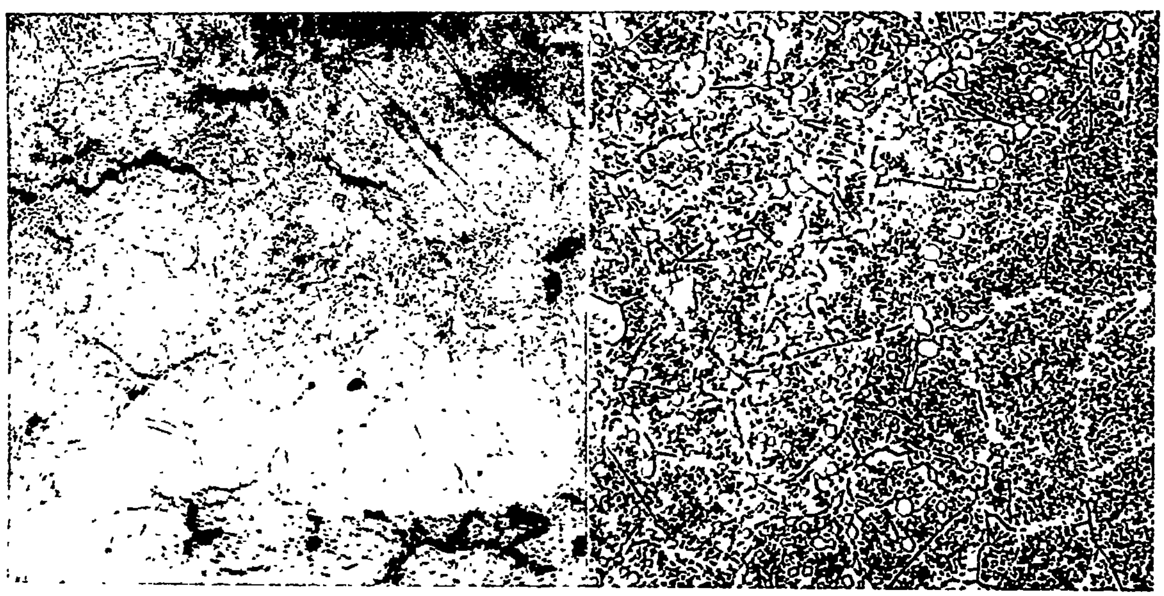
(b) Radial section near center of disc in Y-plane.

Figure 22.- Original microstructures of disc C0713 of Timken alloy.



100X 1000X

(a) Creep specimen IX; 1124 hours under 25,000 psi.

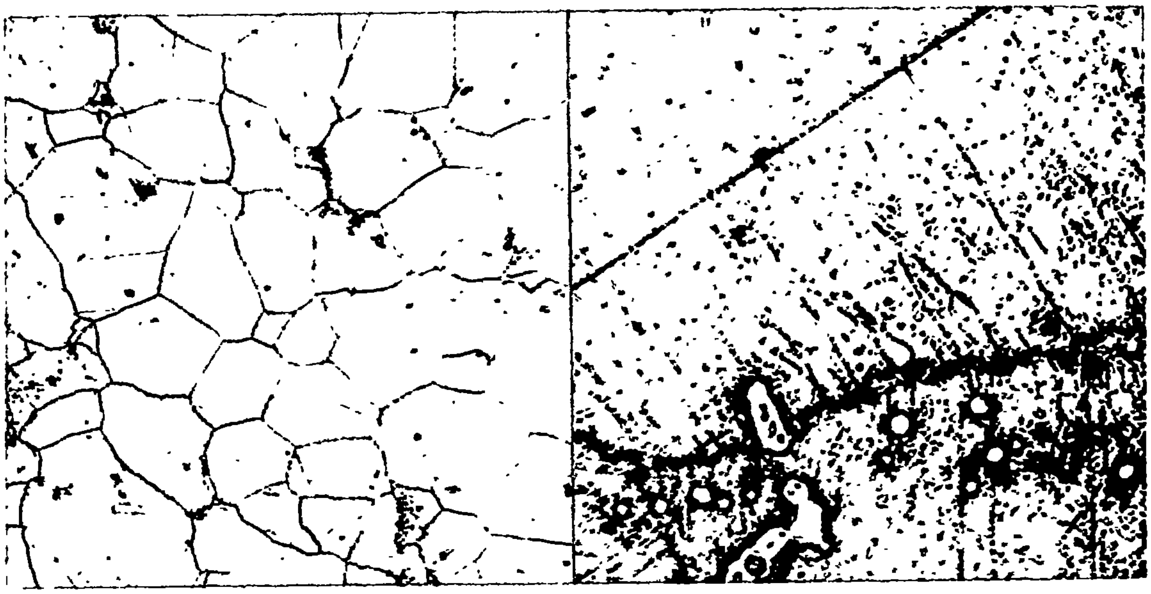


Fracture – 100X Interior – 1000X

(b) Rupture specimen IY; 1295.5 hours for rupture under 30,000 psi.

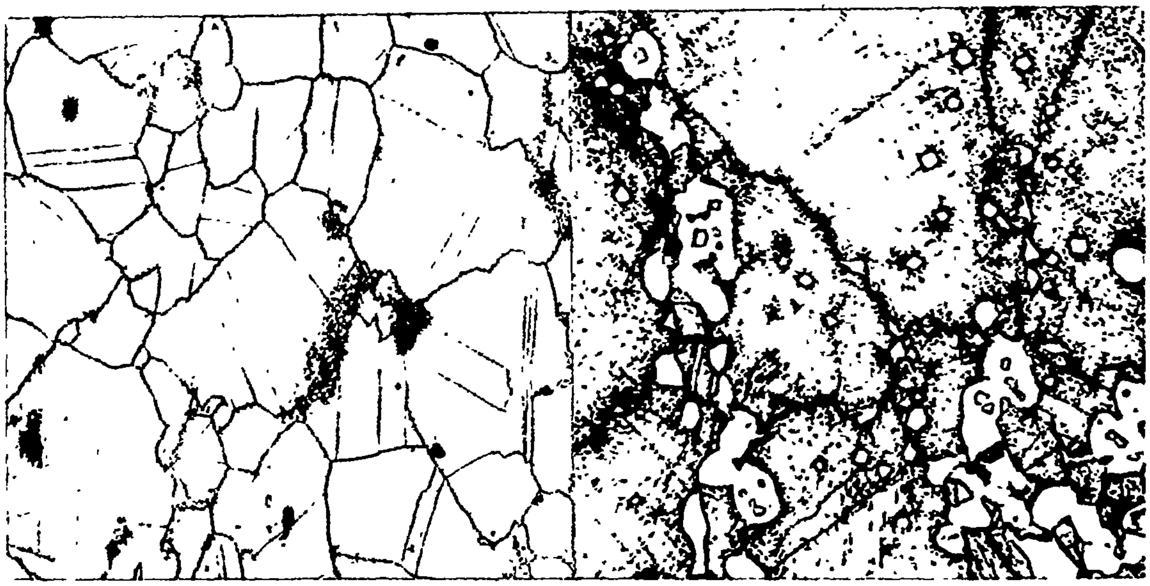
NACA

Figure 23.– Microstructures of completed 1200° F creep- and rupture-test specimens from disc C0713 of Timken alloy.



100X 1000X

(a) Radial section near rim of disc in Y-plane.



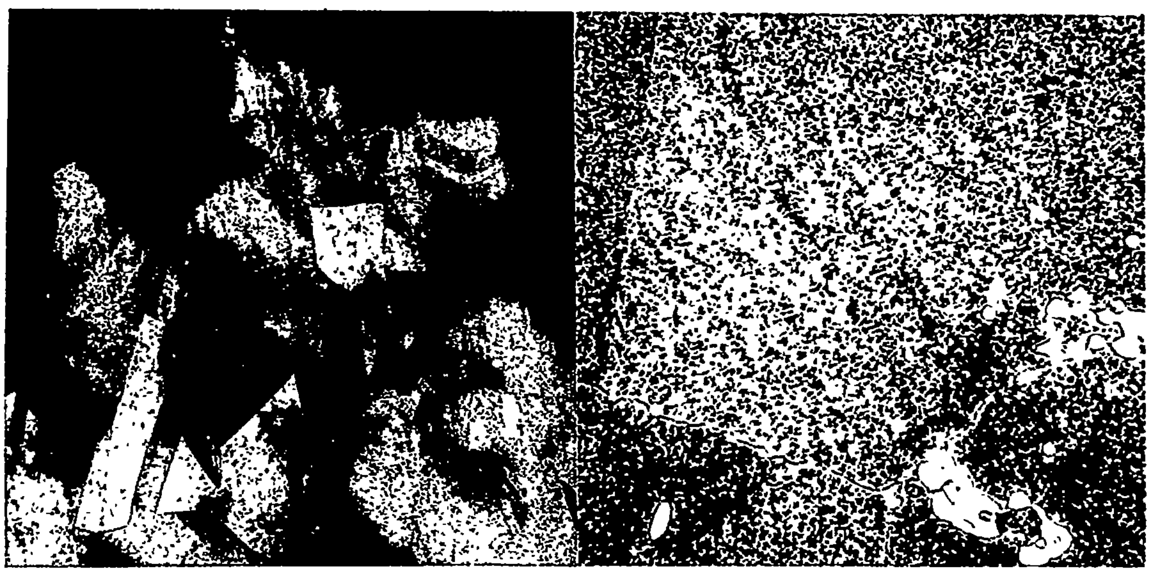
100X 1000X

(b) Radial section near center of disc in Y-plane.

Figure 24.- Original microstructure of disc C3B-441 of Timken alloy.

100X 1000X

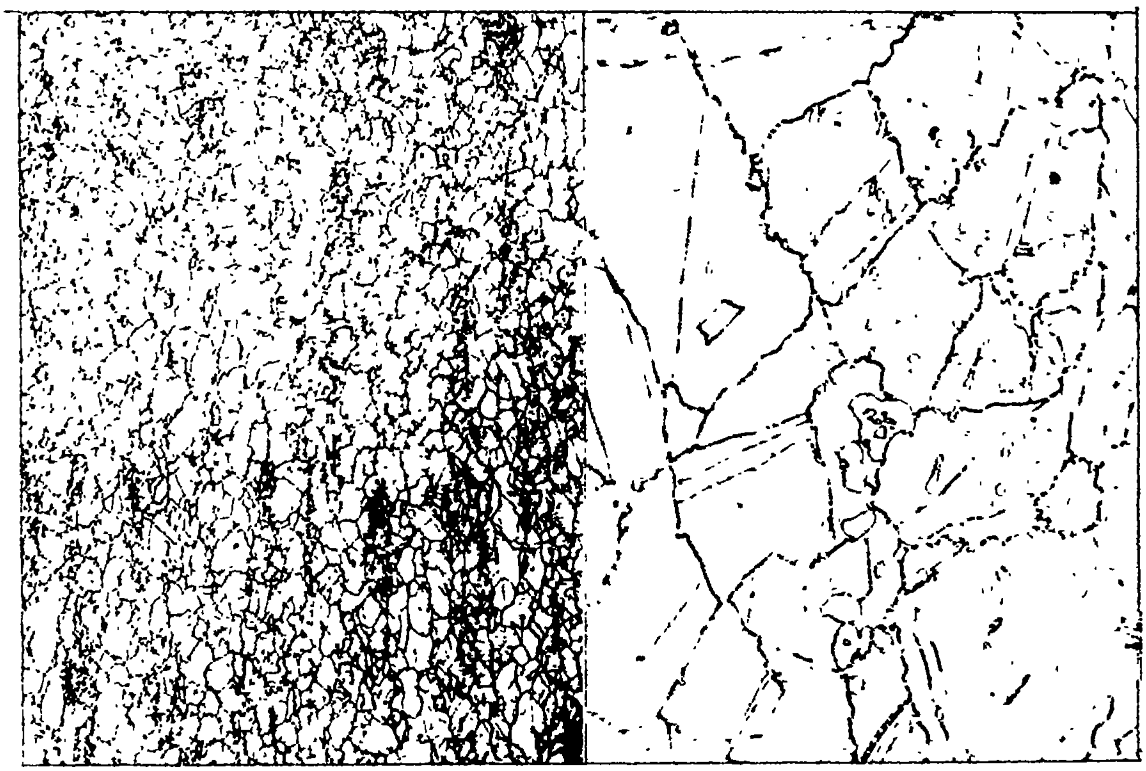
(a) Creep specimen IX; 1290 hours under 25,000 psi.



Fracture – 100X Interior – 1000X

(b) Rupture specimen 3Y; 2401 hours for rupture under 31,000 psi.

Figure 25.– Microstructures of completed 1200° F creep– and rupture–test specimens from disc C3B–441 of Timken alloy.



100X 1000X

Radial section midway between rim and center of disc.

Figure 26.– Original microstructure of disc H-4174-7A of Timken alloy.

100X 1000X

(a) Creep specimen 3Y; 1002 hours under 25,000 psi.

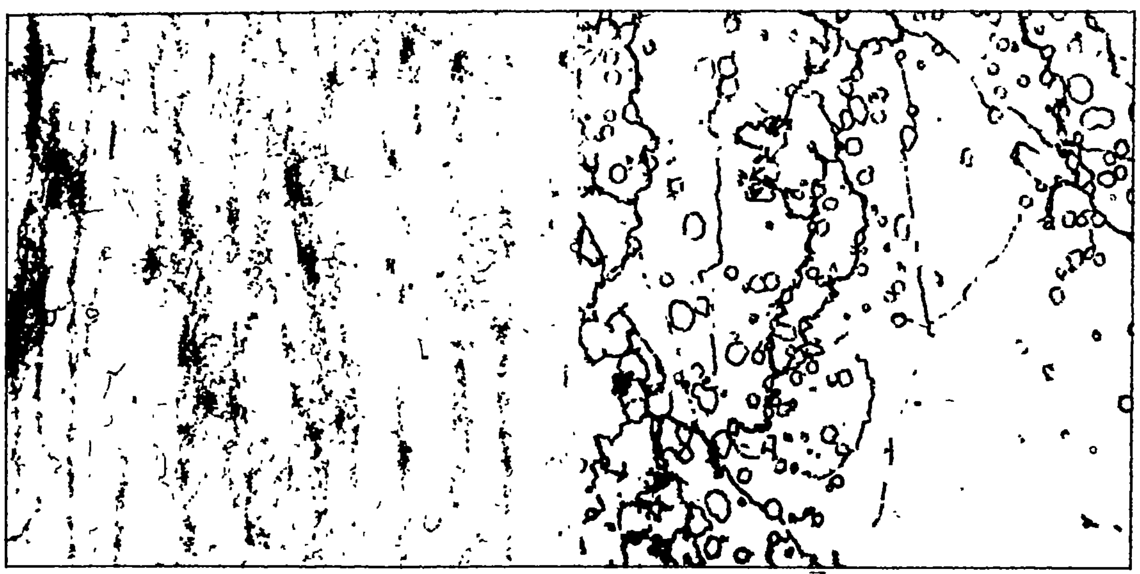
Fracture – 100X Interior – 1000X

(b) Rupture specimen 2Y; 424 hours for rupture under 35,000 psi.

Figure 27.– Microstructures of completed 1200° F creep– and rupture–test specimens from disc H–4174–7A of Timken alloy.

100X 1000X

(a) Radial section near rim of disc in Y-plane.



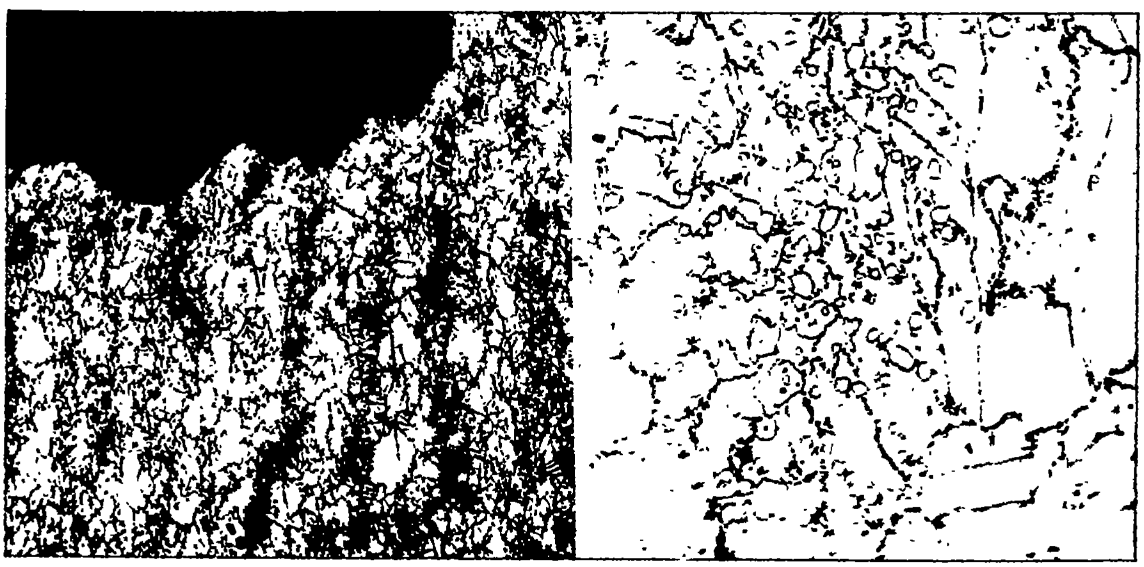
100X 1000X

(b) Radial section near center of disc in Y-plane.

Figure 28.– Original microstructure of disc S1509 of Timken alloy.

100X 1000X

(a) Creep specimen 2Y; 1004 hours under 25,000 psi.



Fracture – 100X Interior – 1000X

(b) Rupture specimen 4Y; 715 hours for rupture under 35,000 psi.

Figure 29.– Microstructures of completed 1200° F creep– and rupture–test specimens from disc S1509 of Timken alloy.